STUDY OF HYPERCHARGE EXCHANGE REACTIONS OF

THE TYPE $0^{-}1/2^{+} \rightarrow 2^{+}1/2^{+}$ AT 4 GeV/c

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ABSTRACT

Results are presented for the quasi two-body hypercharge exchange reactions of the type $0^{-}1/2^{+} \rightarrow 2^{+}1/2^{+}$:

$$\pi^{-}p \rightarrow K^{0}(1420)(\Lambda, \Sigma^{0}),$$

$$K^{-}p \rightarrow f^{0}(1270)(\Lambda, \Sigma^{0}),$$

$$K^{-}p \rightarrow f'(1515)(\Lambda, \Sigma^{0}),$$

using data from two high statistics bubble chamber experiments. The total and differential cross sections are presented and compared with those obtained for the corresponding vector meson reactions and with simple phenomenological ideas.

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1. INTRODUCTION

Although in the last few years the Amsterdam-CERN-Nijmegen-Oxford and CERN-Collège de France-Madrid-Stockholm Collaborations have analyzed many quasi two-body hypercharge exchange reactions in a large variety of spin configurations [1], the study of processes in the spin class $0^{-}1/2^{+} \rightarrow 2^{+}1/2^{+}$ has been limited to partial analyses of the reactions $K^{-}p \rightarrow f'\Lambda$ and $K^{-}p \rightarrow A_2\Lambda$ [2,3].

In this paper we present an analysis of the reactions

$$\pi^{-}p \rightarrow K^0(1420)\Lambda, \quad (A)$$

$$\pi^{-}p \rightarrow K^0(1420)\Sigma^0, \quad (B)$$

$$K^{-}p \rightarrow f^0(1270)\Lambda, \quad (C)$$

$$K^{-}p \rightarrow f^0(1270)\Sigma^0, \quad (D)$$

$$K^{-}p \rightarrow f'(1515)\Lambda, \quad (E)$$

$$K^{-}p \rightarrow f'(1515)\Sigma^0, \quad (F)$$

using data from two high statistics hydrogen bubble chamber experiments ($\pi^{-}p$ at 3.95 GeV/c and $K^{-}p$ at 4.2 GeV/c).

Because of limited statistics and the greater number of parameters required for a full analysis, the results presented here will be less complete than those obtained in other quasi two-body reactions. Nevertheless, they appear to us sufficiently interesting to warrant their publication.

A brief experimental description of the relevant final states is given in sect. 2. In sect. 3 the methods used in the determination of the total cross sections are discussed. In sect. 4 the differential cross sections are presented. Finally, sect. 5 is devoted to a phenomenological discussion of the results. Some concluding remarks are made in sect. 6.

2. DESCRIPTION OF FINAL STATES

The data used for the analysis of the reactions (A)-(F) come from several exposures of the CERN 2m hydrogen bubble chamber to π^{-} and K^{-}

meson beams of average momentum 3.95 GeV/c and 4.15 GeV/c respectively. The statistical sensitivities being ~ 90 events/ μb for the π^- sample and ~ 128 events/ μb for the K^- sample. The events used for this paper are found in the 2-prong + vee topology.

We have extracted the reactions (A)-(F) from events with a visible Λ decay and kinematically compatible with the final states

$$\pi^- p \rightarrow \Lambda K^+ \pi^- \quad 3553 \text{ events} \quad (3915 \text{ events}), \quad (1)$$

$$\pi^- p \rightarrow \Sigma^0 K^+ \pi^- \quad 1619 \text{ events} \quad (1765 \text{ events}), \quad (2)$$

$$K^- p \rightarrow \Lambda \pi^+ \pi^- \quad 22\,886 \text{ events} \quad (25\,658 \text{ events}), \quad (3)$$

$$K^- p \rightarrow \Sigma^0 \pi^+ \pi^- \quad 9394 \text{ events} \quad (10\,473 \text{ events}), \quad (4)$$

$$K^- p \rightarrow \Lambda K^+ K^- \quad 4424 \text{ events} \quad (4889 \text{ events}), \quad (5)$$

$$K^- p \rightarrow \Sigma^0 K^+ K^- \quad 2341 \text{ events} \quad (2551 \text{ events}), \quad (6)$$

where the quoted number of events refer to the final samples used in the analysis after applying appropriate selection criteria. In parenthesis we give the corresponding number of events weighted to account for losses due to Λ decays occurring outside the fiducial volume or too close to the production vertex (< 3 mm).

The procedures for the selection of samples of events for the final states (1)-(6), as well as other experimental details, are given in refs [1(b)] and [1(j)]. In general, they resulted in a preference for the more highly constrained hypothesis.

The cross sections corrected for throughput efficiencies and unseen decay modes were calculated to be

$$\sigma(\pi^- p \rightarrow \Lambda K^+ \pi^-) = 79 \pm 3 \mu\text{b},$$

$$\sigma(\pi^- p \rightarrow \Sigma^0 K^+ \pi^-) = 35 \pm 2 \mu\text{b},$$

$$\sigma(K^- p \rightarrow \Lambda \pi^+ \pi^-) = 312 \pm 15 \mu\text{b},$$

$$\sigma(K^- p \rightarrow \Sigma^0 \pi^+ \pi^-) = 120 \pm 6 \mu\text{b},$$

$$\sigma(K^- p \rightarrow \Lambda K^+ K^-) = 67 \pm 3 \mu\text{b},$$

$$\sigma(K^- p \rightarrow \Sigma^0 K^+ K^-) = 33 \pm 2 \mu\text{b}.$$

3. TOTAL CROSS SECTIONS

3.1 The reaction $\pi^- p \rightarrow K^0(1420)\Lambda$

The total cross section for this reaction was obtained from a maximum likelihood analysis of the Dalitz plot $M^2(K^+\pi^-)$ vs $M^2(\Lambda\pi^-)$ shown in fig. 1. The dominant feature of the final state $\pi^- p \rightarrow \Lambda K^+\pi^-$ is the strong production of $K^0(890)$, $K^0(1420)$, $\Sigma^-(1385)$ and $N(1700)$ resonances. A detailed study of the processes $\pi^- p \rightarrow K^0(890)\Lambda$ and $\pi^- p \rightarrow K^+\Sigma^-(1385)$ has been presented elsewhere [1(j)] and [1(k)].

The probability function used in the fit contained terms describing the production (Breit-Wigner shapes) and decay distribution (expanded in terms of diagonal s-channel helicity density matrix elements) of the contributing resonances. A phase-space term was also included. The details of the fit are given in table 1 and the projections on the $K^+\pi^-$, $\Lambda\pi^-$ and ΛK^+ effective mass distributions are shown in fig. 2. As can be seen, the different distributions are well reproduced by the fit. The number of $K^0(1420)$ events obtained was 431 ± 38 and the production cross section corrected for Λ unseen decay modes and other $K^0(1420)$ decay modes [4] was calculated to be

$$\sigma(\pi^- p \rightarrow K^0(1420)\Lambda) = 27 \pm 3 \text{ } \mu\text{b.}$$

This value is in good agreement with the value $29 \pm 2 \text{ } \mu\text{b}$ obtained in ref. [1(j)] from the study of the $K^+\pi^-$ effective mass distribution. The cross section for this reaction has been previously measured at 4.5 GeV/c [5]. The corrected value $34 \pm 5 \text{ } \mu\text{b}$ is consistent with our determination.

3.2 The reaction $\pi^- p \rightarrow K^0(1420)\Sigma^0$

The final state $\pi^- p \rightarrow \Sigma^0 K^+\pi^-$ is clearly dominated by the $K^0(890)$ and $K^0(1420)$ resonance production. As the Dalitz plot $M^2(K^+\pi^-)$ vs $M^2(\Sigma^0\pi^-)$ and the $K^+\pi^-$, $\Sigma^0\pi^-$ and $\Sigma^0 K^+$ effective mass distributions presented in figs 3 and 4 show, no significant resonance in the $\Sigma^0\pi^-$ or $\Sigma^0 K^+$ systems is detected. We then give for the production of the $K^0(1420)$ the results obtained in ref. [1(j)] from a fit to the $K^+\pi^-$ effective mass distribution with a form which included Breit-Wigner functions together with a third order polynomial for the background. The number of $K^0(1420)$ events obtained in the fit was 170 ± 34 and the cross section

$$\sigma(\pi^- p \rightarrow K^0(1420)\Sigma^0) = 10 \pm 2 \text{ } \mu\text{b}.$$

This cross section has been measured at 4.5 GeV/c and the value $11 \pm 2 \text{ } \mu\text{b}$ obtained [5].

We close this section by remarking that associated production of $K^0(1420)$ with Λ or Σ^0 are processes with much smaller cross sections than $K^0(1420)$ production by charge exchange or diffraction dissociation. The values $\sigma(K^- \rightarrow K^0(1420)n) = 570 \pm 108 \text{ } \mu\text{b}$ and $\sigma(K^- p \rightarrow K^-(1420)p) = 246 \pm 51 \text{ } \mu\text{b}$ have been obtained at 3.9 GeV/c [6].

3.3 The reaction $K^- p \rightarrow f^0(1270)\Lambda$

An idea of the complexity of the channel $K^- p \rightarrow \Lambda\pi^+\pi^-$ can be obtained by observing the $M^2(\Lambda\pi^+) \text{ vs } M^2(\pi^+\pi^-)$ Dalitz plot and the $\pi^+\pi^-$, $\Lambda\pi^+$ and $\Lambda\pi^-$ effective mass distributions shown in figs 5 and 6. The $\rho(770)$ and $f(1270)$ meson resonances appear as prominent structures of the $\pi^+\pi^-$ system. In previous publications the properties of the ρ meson were studied in detail [1(b),7], emphasizing (among other things) the ρ - ω interference pattern and the interference of the resonance with an important underlying s-wave background. In the $\Lambda\pi^+$ effective mass plot the very strong production of $\Sigma^+(1385)$ is clearly seen. In the mass region centred at ~ 1700 MeV a large accumulation of events is observed. As it is known, different $\Sigma(1660)$ states contribute to this $\Lambda\pi^+$ mass region [4,8]. A small but noticeable structure at around 2000 MeV is also seen. In the $\Lambda\pi^-$ mass projection, the $\Sigma^-(1385)$ is the only resonance significantly produced. The production and decay properties of the $\Sigma^\pm(1385)$ states have been presented elsewhere [1(d)].

As fig. 5 shows, the $f^0(1270)$ band overlaps with all the Σ resonances. This is more clearly seen in fig. 7 where we present the $\Lambda\pi^+$ and $\Lambda\pi^-$ effective mass distributions for the events in the f^0 band (defined by $1.14 < M(\pi^+\pi^-) < 1.40$ GeV). Copious production of $\Sigma^\pm(1385)$ and $\Sigma^\pm(1700)$ is observed. These resonances reflect in the $f^0(1270)$ polar s-channel helicity decay distribution introducing important distortions affecting a large range of this distribution (fig. 8).

In view of these difficulties, the natural procedure to obtain a measurement of the cross section for $f^0(1270)$ production is to perform a quantitative analysis of the $M(\pi^+\pi^-)$ vs $M(\Lambda\pi^+)$ scatter diagram for the final state $K^-p \rightarrow \Lambda\pi^+\pi^-$ including parametrizations for all the competing reactions. A basic problem when dealing with competing processes overlapping in the phase space is the possible existence of interference phenomena among the amplitudes describing them. As it will be discussed later, a reasonable representation of the density of events in the $M(\pi^+\pi^-)$ vs $M(\Lambda\pi^+)$ diagram can be obtained neglecting the interferences between the resonances contributing to the final state with the exception of the $\rho(770)$ which, as already mentioned, exhibits important interference effects with the underlying $\pi^+\pi^-$ s-wave. Although the relevance of the s-wave in the $f^0(1270)$ mass region is poorly known, we have included its possible contribution and interference effects in the formulation of the probability function.

The parametrization of the different processes contributing to the final state $K^-p \rightarrow \Lambda\pi^+\pi^-$ was made using Breit-Wigner functions [9] and expansions of the polar s-channel helicity decay distributions in terms of the diagonal density matrix elements [10]. For the $\pi^+\pi^-$ s-wave, we will assume resonance shapes near the $\rho(770)$ and $f^0(1270)$ positions (ϵ and ϵ' respectively) and the interferences will be parametrized using generalized density matrix elements [11]. In general, the values of the resonance parameters (mass and width) were taken from the Review of Particle Properties [4].

Since in this paper we are mainly concerned with the study of 2^+ mesons, we neglected the ρ - ω interference effects and used the results of an effective parametrization, denoted as fit 1 in ref. [7] ($M(\rho) = 760 \pm 2$ MeV, $\Gamma(\rho) = 101 \pm 7$ MeV, $M(\epsilon) = 782 \pm 7$ MeV, $\Gamma(\epsilon) = 530 \pm 60$ MeV), which gave an acceptable description of the $\pi^+\pi^-$ line shape in this mass region. For the ϵ' we used as starting parameters $M = 1300$ MeV, $\Gamma = 180$ MeV [4]. As we will see later, our data requires little or no ϵ' and the solution is insensitive to the precise resonance parameters. For the structure at $M(\Lambda\pi) \sim 1700$ MeV we used a single Breit-Wigner function.

The fit to the diagram $M(\pi^+\pi^-)$ - $M(\Lambda\pi^+)$ was made using a least squares method. The two-dimensional distribution was divided in cells of 100×100 MeV². The parameters of the fit were the resonance fractions

and density matrix elements, although we also checked that the results did not depend significantly on the values of M and Γ . A summary of the more relevant results obtained in the best fit are given in table 2. In fig. 9 we compare the results of the solution with the actual number of observed events. The overall χ^2 is 352 for 222 cells. The projections of this solution on the $\pi^+\pi^-$, $\Lambda\pi^+$ and $\Lambda\pi^-$ effective mass distributions are shown in fig. 6. The following χ^2 were obtained from these spectra

$$M(\pi^+\pi^-) : \chi^2 = 104 \text{ for 80 intervals,}$$

$$M(\Lambda\pi^+) : \chi^2 = 98 \text{ for 80 intervals,}$$

$$M(\Lambda\pi^-) : \chi^2 = 78 \text{ for 79 intervals.}$$

As the value of the overall χ^2 reflects, the fit gives a reasonable description of the main features of the $M(\pi^+\pi^-)$ - $M(\Lambda\pi^+)$ distribution. A significant contribution to the total χ^2 is due to cells located in the border of the distribution (a χ^2 of 57 for 11 cells). This is partly due to the fact that in the least squares method we calculated the theoretical number of events in each cell using the average value of the total c.m. energy, without taking into account that the data were obtained in several exposures to K^- beams at momenta from 4.09 to 4.25 GeV/c. In view of this simplification and taking into account that we are ignoring the ρ - ω interference effect and are using an approximate form of the $\pi^+\pi^-$ s-wave, the results of the fit appear to be satisfactory. We have projected the results of the best fit on the decay angular distribution in the $f^0(1270)$ mass region (fig. 8) and obtained good agreement. This indicates that in the $f^0(1270)$ band any interference effects are small, although there is a large overlap with competing Σ resonances.

Using the fraction for the $f^0(1270)$ production and correcting for unseen resonance decay modes [4] we obtain the following value of the cross section

$$\sigma(K^-p \rightarrow \Lambda f^0(1270)) = 77 \pm 6 \text{ } \mu\text{b.}$$

We have also performed a measurement of this cross section assuming a polynomial representation for the reflections due to resonances coupled to the $\Lambda\pi^\pm$ systems. An acceptable fit ($\chi^2 = 119$ for 80 intervals) is

obtained with a fifth-order polynomial. The cross section obtained with this method is

$$\sigma(K^- p \rightarrow \Lambda f^0(1270)) = 76 \pm 4 \text{ } \mu\text{b}$$

in agreement with the determination based on the detailed analysis of the $\Lambda\pi^+\pi^-$ Dalitz plot.

The cross section for this process has been measured in this energy range at several K^- momenta. Based on much smaller statistics the values $45 \pm 12 \text{ } \mu\text{b}$, $62 \pm 27 \text{ } \mu\text{b}$, $98 \pm 4 \text{ } \mu\text{b}$, $60 \pm 8 \text{ } \mu\text{b}$ and $15 \pm 6 \text{ } \mu\text{b}$ were obtained at 3.9 GeV/c, 3.95 GeV/c, 4.10 GeV/c and 5.5 GeV/c respectively [12].

We close this section by commenting on the small value of the $\pi^+\pi^-$ s-wave under the $f^0(1270)$. The most reliable information on this state has been obtained from high statistics data on the reactions $\pi^- p \rightarrow K_s^0 K_s^0 n$ [13,14] and $\pi^- p \rightarrow K^+ K^- n$ and $\pi^+ n \rightarrow K^+ K^- p$ [15]. The more relevant information for the study of the s-wave was contained in the structure of the variable $\sqrt{4\pi} \langle Y_0^2 \rangle d^2 \sigma / dt dM$, which showed a dramatic interference pattern. We have calculated the even moments Y_M^L of the $\pi^+\pi^-$ system removing the range of the decay distribution distorted by Σ^{*+} reflections ($-1.0 < \cos \theta_{\pi\pi}^{SH} < 0.0$, where $\theta_{\pi\pi}^{SH}$ is the polar s-channel helicity decay angle of the $\pi^+\pi^-$ system) in the peripheral sector $0.5 < \cos \theta_{p-\Lambda} < 1.0$ ($\theta_{p-\Lambda}$ being the angle between the target proton and outgoing Λ in the overall c.m.). These distributions show smooth behaviour in the f^0 region indicating that our context is essentially different from the one of reactions $\pi p \rightarrow K\bar{K}n$, so that a clear contribution from s-d interferences cannot be isolated.

3.4 The reaction $K^- p \rightarrow f^0(1270)\Sigma^0$

We give in figs 10 and 11 the $M^2(\Sigma^0\pi^+) - M^2(\pi^+\pi^-)$ Dalitz plot and the $\pi^+\pi^-$, $\Sigma^0\pi^+$ and $\Sigma^0\pi^-$ effective mass distributions. The following features are observed. In the $\pi^+\pi^-$ system strong production of both $\rho(770)$ and $f^0(1270)$ resonances is seen. The $\Sigma^0\pi^+$ effective mass distribution exhibits a $\Sigma(1660)$ signal which has been already studied by the ACNO Collaboration [8]. Besides the small $\Sigma(1385)$ signal an enhancement is seen at 1460 MeV. In fig. 12 we show this histogram in 10 MeV bins (the mass resolution being of this order); the 1460 MeV enhancement stands very

clearly. It has been argued in earlier observations [8] that this effect is probably caused by a small contamination from $\Sigma(1385) \rightarrow \Lambda\pi^+$ decay in the final state $K^-p \rightarrow \Lambda\pi^+\pi^-$. We have investigated in some detail the nature of this bump. In particular, it cannot be removed by imposing restrictive probability or missing mass (against the $\Lambda\pi^+\pi^-$ or $\pi^+\pi^-$ system) cuts. It is also associated to unique events (events for which the χ^2 probability of the $\Lambda\pi^+\pi^-$ hypothesis is smaller than 0.1%) and the standard distributions for separating Λ - Σ^0 events (cosine of the angles between the Λ in the Σ^0 rest frame and the Σ^0 line-of-flight or production normal) show the isotropy expected for real Σ^0 events. In view of the difficulty of removing this enhancement, and without arguing in favour of a new Σ state, a term representing its production will be included in the probability function used in the analysis described below. The $\Sigma^0\pi^-$ histogram shows some $\Sigma(1660)$ production and again a small accumulation of events in the 1460 MeV mass region.

Since, as figs 13 and 14 clearly show, the resonances coupled to the $\Sigma^0\pi^+$ system reflect strongly in the f^0 region, the cross section for the $K^-p \rightarrow \Sigma^0 f^0(1270)$ process has been extracted from a fit to the $M(\pi^+\pi^-) - M(\Sigma^0\pi^+)$ diagram following the method discussed in sect. 3.3. The diagram was divided in cells of 125×125 MeV².

A summary of the final results obtained using a least squares method is given in table 3. The overall χ^2 is 165 for 137 cells and the projections of the best solution are given in figs 11 and 15. The following χ^2 were obtained from the effective mass distributions

$$M(\pi^+\pi^-) : \chi^2 = 94 \text{ for 78 intervals,}$$

$$M(\Sigma^0\pi^+) : \chi^2 = 80 \text{ for 77 intervals,}$$

$$M(\Sigma^0\pi^-) : \chi^2 = 79 \text{ for 77 intervals,}$$

The overall fit is again reasonable and the individual effective mass distributions are well reproduced by the projection of the fit. The larger contribution to the χ^2 come from cells in the border of the Dalitz plot (which is probably due to the fact that we are using an average value of the total c.m. energy).

From the fraction of $f^0(1270)$ we obtain the following value of the total cross section, corrected for Λ visibility and unseen resonance decay modes

$$\sigma(K^- p \rightarrow \Sigma^0 f^0(1270)) = 26 \pm 3 \text{ } \mu\text{b},$$

which is in excellent agreement with the value

$$\sigma(K^- p \rightarrow \Sigma^0 f^0(1270)) = 25 \pm 3 \text{ } \mu\text{b}$$

obtained from a fit to the $\pi^+ \pi^-$ mass distribution assuming a fifth-order polynomial for the reflections of the resonances coupled to the $\Sigma^0 \pi^\pm$ systems.

Measurements of this cross section have been performed at 3.9 GeV/c, 3.95 GeV/c and 4.5 GeV/c. The values $25 \pm 9 \text{ } \mu\text{b}$, $31 \pm 15 \text{ } \mu\text{b}$ and $15 \pm 5 \text{ } \mu\text{b}$ were, respectively, obtained [12].

The cross sections for $f^0(1270)$ hypercharge exchange production are much smaller than the cross section measured in the one-pion exchange process $\pi^- p \rightarrow f^0(1270)n$, where the value $983 \pm 104 \text{ } \mu\text{b}$ was obtained at 4.16 GeV/c [16].

3.5 The reaction $K^- p \rightarrow f'(1515)\Lambda$

The reactions $K^- p \rightarrow f'(1515) (\Lambda, \Sigma^0)$ have been already studied by the ACNO Collaboration using a sensitivity of approximately 100 events/ μb [2]. The final states mainly considered in that analysis were

$$K^- p \rightarrow K_S^0 K_S^0 (\Lambda, \Sigma^0).$$

In this paper we will concentrate the interest in the channels

$$K^- p \rightarrow K^+ K^- (\Lambda, \Sigma^0),$$

which are statistically richer, although interference effects among the resonances coupled to the $K^+ K^-$ system are expected to be larger [17]. The reactions $K^- p \rightarrow \phi (\Lambda, \Sigma^0)$ have been studied in ref. [1(b)] using these channels.

As the Dalitz plot $M^2(K^+K^-)$ vs $M^2(\Lambda K^-)$ and the effective mass distributions of the K^+K^- , ΛK^+ and ΛK^- systems of the final state $K^-p \rightarrow \Lambda K^+K^-$ show (figs 16 and 17) this reaction is dominated by the production of K^+K^- resonances, although the $E(1820)$ (and perhaps the $E(2030)$) is also produced with an important cross section [18].

To extract the cross section for the process $K^-p \rightarrow f'(1515)\Lambda$ we have followed the method of ref. [2] and fitted the K^+K^- mass spectrum, which has a substantial shoulder on the low mass side of the $f'(1515)$, using three completely coherent Breit-Wigners for the $f^0(1270)$, $A_2(1300)$, $f'(1515)$, which are added incoherently to a Breit-Wigner for the $\phi(1020)$ and a polynomial background. The probability function used was

$$f(m) = \alpha_1 |BW(\phi)|^2 + \alpha_2 |BW(f') + \beta_1 e^{i\phi_1} BW(f^0) + \beta_2 e^{i\phi_2} BW(A_2)|^2 + (1-\alpha_1-\alpha_2) P(m)$$

with

$$BW = \frac{M_0 \Gamma_0}{m^2 - M_0^2 - i M_0 \Gamma} \left(\frac{q}{q_0} \right), \quad \Gamma = \Gamma_0 \frac{M_0}{m} \left(\frac{q}{q_0} \right)^{2\ell+1}.$$

The resonance parameters for the f^0 and A_2 were fixed to the Particle Data Group (PDG) values [4]. The result of the fit is displayed in fig. 17(a). The following values were obtained for the parameters of the $f'(1515)$

$$M_0 = 1521 \pm 6 \text{ MeV},$$

$$\Gamma_0 = 85 \pm 16 \text{ MeV}.$$

The fit gives 100 ± 44 , 59 ± 24 and 650 ± 100 events for the $f^0(1270)$, $A_2(1300)$ and $f'(1515)$ respectively. From these numbers and using the branching ratios for the unseen decays given in ref. [4] we obtain the following cross sections:

$$\sigma(K^-p \rightarrow f^0(1270)\Lambda) = 92 \pm 40 \text{ } \mu\text{b},$$

$$\sigma(K^-p \rightarrow A_2(1310)\Lambda) = 36 \pm 15 \text{ } \mu\text{b},$$

$$\sigma(K^-p \rightarrow f'(1515)\Lambda) = 19 \pm 3 \text{ } \mu\text{b}.$$

Within large errors the determination of the $f^0(1270)$ cross section from the K^+K^- decay mode is compatible with the one obtained in sect. 3.3 using the dominant $\pi^+\pi^-$ decay mode. For the $A_2(1300)$ we have calculated the integrated cross section for $|t| < 1 \text{ GeV}^2$ using the method discussed above. A value of $23 \pm 13 \text{ } \mu\text{b}$ is obtained. Within its large error, it is compatible with the value $22.3 \pm 2.2 \text{ } \mu\text{b}$ obtained, after correcting for other decay modes, in a partial wave analysis of the 3π system in the final state $\Lambda\pi^+\pi^-\pi^0$ [3].

The cross section obtained here for the reaction $K^-p \rightarrow f'\Lambda$ agrees with that obtained earlier [2] from analysis of the $\Lambda K_s^0 K_s^0$ final state: $\sigma(f'\Lambda) = 13 \pm 2 \text{ } \mu\text{b}$. The same is true for the mass and width of the f' , which were then found to be $M_0 = 1522 \pm 6 \text{ MeV}$, $\Gamma_0 = 62^{+19}_{-14} \text{ MeV}$.

It is appropriate to remark that although the data on the $f' \rightarrow K^+K^-$ mode are 4.5 times larger than that for the $f' \rightarrow K_s^0 K_s^0$ mode, the latter have the advantage of being less affected by interference effects [17].

In this energy range the $f'(1515)$ cross section has been measured at 3.9, 3.95 and 4.6 GeV/c. The values $7 \pm 4 \text{ } \mu\text{b}$, $24 \pm 6 \text{ } \mu\text{b}$ and $19 \pm 4 \text{ } \mu\text{b}$ were, respectively, obtained [12].

3.6 The reaction $K^-p \rightarrow f'(1515)\Sigma^0$

The Dalitz plot distribution $M^2(\Sigma^0 K^-)$ vs $M^2(K^+ K^-)$ and the $K^+ K^-$, $\Sigma^0 K^+$ and $\Sigma^0 K^-$ effective mass distributions for the reaction $K^-p \rightarrow \Sigma^0 K^+ K^-$ given in figs 18 and 19, show clear ϕ and f' production. Interference effects between the f^0 - A_2 - f' are difficult to detect in this reaction but a good fit to the $K^+ K^-$ effective mass spectrum can be obtained by considering an incoherent superposition of the three corresponding Breit-Wigners with resonance parameters fixed to the values given in sect. 3.5. A Breit-Wigner for the ϕ and a polynomial background were also included in the fit. The number of $f'(1515)$ events obtained in this way is 166 ± 33 and the cross section is

$$\sigma(K^-p \rightarrow f'(1515)\Sigma^0) = 4.3 \pm 0.8 \text{ } \mu\text{b},$$

which is compatible with the value $5.0 \pm 1.1 \text{ } \mu\text{b}$ obtained in ref. [2] from the $K_s^0 K_s^0$ decay mode.

For the f^0 and A_2 cross sections we have obtained the values

$$\sigma(K^- p \rightarrow f^0 \Sigma^0) = 16 \pm 8 \text{ } \mu\text{b},$$

$$\sigma(K^- p \rightarrow A_2 \Sigma^0) = 10 \pm 9 \text{ } \mu\text{b}.$$

Within the large errors the f^0 cross section is compatible with the value obtained in sect. 3.4.

4. DIFFERENTIAL CROSS SECTIONS

4.1 The reaction $\pi^- p \rightarrow K^0(1420)\Lambda$

The production properties of the $K^0(1420)$ in the reaction $\pi^- p \rightarrow K^0(1420)\Lambda$ are illustrated by the Chew-Low distribution $M^2(K^+ \pi^-) - t(p, \Lambda)$ given in fig. 20. The $K^0(1420)$ is produced strongly at low t values. To calculate its differential cross section we have fitted the $K^+ \pi^-$ effective mass distribution, for various intervals of t' , with a form which includes Breit-Wigner functions for the $K^0(890)$ and $K^0(1420)$ and a polynomial for the background. The differential cross section obtained in this way is given in table 4 and fig. 21. It drops steeply up to $t' < 0.3 \text{ GeV}^2$ when it appears to flatten out. The shape is very different from that measured for the $K^0(890)$ in this experiment and which is also shown in fig. 21.

The backward to total cross section ratio for $K^0(1420)$ production is $9 \pm 4\%$ (for $K^0(890)$ production this ratio is $8 \pm 1\%$).

4.2 The reaction $\pi^- p \rightarrow K^0(1420)\Sigma^0$

The Chew-Low distribution $M^2(K^+ \pi^-) - t(p, \Sigma^0)$, given in fig. 22, indicates the presence both of forward and backward $K^0(1420)$ production. The differential cross section, calculated using a similar method to the one outlined in sect. 4.1, is given in table 5 and plotted in fig. 23. It shows little variation with t . Both its magnitude and shape are very different from that of the $K^0(890)$ shown in the same figure.

The backward to total cross section ratio for $K(1420)$ production has been measured to be $37 \pm 11\%$ (for $K^0(890)$ production this ratio is $10 \pm 1\%$).

4.3 The reaction $K^- p \rightarrow f^0(1270)\Lambda$

An interesting feature of the $K^- p \rightarrow f^0(1270)\Lambda$ reaction is the copious production of $f^0(1270)$ in the backward direction. This is illustrated in Fig. 24 showing the Chew-Low plot $M^2(\pi^+\pi^-)-t(p,\Lambda)$. In the $f^0(1270)$ mass band, the $\pi^+\pi^-$ system is produced both in the backward and forward hemispheres. Figs 25 and 26 give an approximate idea of how the $f^0(1270)$ is produced. In the backward hemisphere, and specially in the sector $-1.0 < \cos\theta_{p-\Lambda} < -0.5$, the f^0 appears to be produced in a cleaner way over a moderately small background. The reflections from Σ hyperons change its size and shape with the production angle. In the most forward sector they are strong and due mainly to the positively charged states. They tend to be smaller in the backward hemisphere and consist mostly of $\Sigma^\pm(1385)$. This is clearly seen in fig. 27 in which the cosine of the s-channel polar helicity decay distribution for events in the $f^0(1270)$ mass region is shown for different intervals of the production variable $\cos\theta_{p-\Lambda}$.

Our approach for calculating the differential cross section of the $f^0(1270)$ is to remove the competing Σ resonances via cuts in the $\pi^+\pi^-$ decay distribution and fit the resulting distributions with incoherent Breit-Wigners for the $\pi^+\pi^-$ resonances and a polynomial background. This approach is justified by the results obtained in sect. 3.3, which indicated that, although the f^0 band overlaps with all Σ^* resonances, no significant f^0 - Σ^* interference appears to exist, and by the good quality of the fits performed under these assumptions. In the forward direction, we have fitted the $\pi^+\pi^-$ effective mass histograms as a function of t' removing the distorted decay hemisphere ($-1.0 < \cos\theta_{\pi\pi}^{SH} < 0.0$). In the backward hemisphere, where distortions are much smaller, we have used the uncut sample. The results of this determination are given in table 6 and fig. 28. The differential cross section is almost symmetrical around $\cos\theta_{p-\Lambda} = 0.0$; the backward to total cross section ratio being $51 \pm 3\%$. For the reaction $K^- p \rightarrow \Lambda\omega$ (its differential cross section is given in fig. 28) the backward cross section is also very important and the measured fraction of cross section in the backward hemisphere was $34 \pm 2\%$. A similar observation has also been made for the reaction $K^- p \rightarrow \omega\Lambda(1520)$ for which the backward to total ratio was measured to be $51 \pm 5\%$. Experimentally, it seems that processes in which an $I = 0$ baryon is produced with a meson belonging to the singlet representation of SU(3) have a very important backward cross section.

4.4 The reaction $K^-p \rightarrow f^0(1270)\Sigma^0$

An idea of the production properties of the $f^0(1270)$ in the reaction $K^-p \rightarrow f^0(1270)\Sigma^0$ is given by the Chew-Low distribution $M^2(\pi^+\pi^-)-t(p,\Sigma^0)$ presented in fig. 29 and by the cosine of the production angle for events in the $f^0(1270)$ region ($1.14 < M(\pi^+\pi^-) < 1.40$ GeV) given in fig. 30. As fig. 31 shows, although there is significant backward production its relative importance is smaller than in the Λ reaction. In the forward hemisphere the reflections from $\Sigma^+(1385)$ and $\Sigma^+(1660)$ are large (fig. 32). To calculate the differential cross section they were removed by selecting events in the forward hemisphere of the polar s-channel helicity decay distribution. In the backward region, the reflections are smaller and were not removed in the analysis. The differential cross section was obtained fitting the resulting effective mass distributions in a way similar to that discussed in sect. 4.3. The results of the analysis are given in table 7 and fig. 33. The backward to total cross section ratio is $25 \pm 5\%$. A measurement of this ratio has been made at 4.93 GeV/c for the reaction $K^-n \rightarrow \omega\Sigma^-$ and the value $17 \pm 7\%$ was obtained [19]. The same experiment found for the reaction $K^-n \rightarrow f^0\Sigma^-$ the value $37 \pm 18\%$ for this backward to total cross section ratio.

4.5 The reaction $K^-p \rightarrow f'(1515)\Lambda$

As the Chew-Low plot $M^2(K^+K^-)$ vs $t(p,\Lambda)$ presented in fig. 34 shows the K^+K^- system is essentially produced at low values of the momentum transfer with small resonance production in the backward region.

To obtain the differential cross section of the $f'(1515)$ we have fitted the K^+K^- effective mass distribution for various intervals of t' using the form discussed in sect. 3.5. The results of the analysis are listed in table 8 and plotted in fig. 35. This determination agrees with that previously obtained in [2]. Although its magnitude is very different from that measured for the ϕ in this experiment (also shown in fig. 35) the shapes are closely similar.

The K^+K^- effective mass distribution in the backward hemisphere is given in fig. 36. Using this histogram we have extracted the following ratios of the backward to total cross section

$$\phi(1020) : 0.7 \pm 0.2\%,$$

$$f'(1515) : < 4\% \text{ (95\% CL)}.$$

4.6 The reaction $K^-p \rightarrow f'(1515)\Sigma^0$

The Chew-Low plot $M^2(K^+K^-)$ vs $t(p, \Sigma^0)$ for the reaction $K^-p \rightarrow K^+K^-\Sigma^0$ is given in fig. 37 and shows that the K^+K^- system is preferentially produced at low t values. The differential cross section calculated fitting the K^+K^- effective mass distribution with the form described in sect. 3.6 is given in table 9 and plotted in fig. 38. Its magnitude is very different from that of the ϕ plotted in the same figure, but its shape is similar.

The K^+K^- effective mass distribution for events in the backward hemisphere, presented in fig. 39, exhibits possibly a small ϕ signal but no excess of events in the f' mass region. Using this histogram we have extracted the following ratios of the backward to total cross section

$$\phi(1020) : 0.6 \pm 0.3\%,$$

$$f'(1515) : < 6\% \text{ (95\% CL)}.$$

5. DISCUSSION OF RESULTS

A general comment concerning the hypercharge exchange reactions $0^{-}1/2^{+} \rightarrow 2^{+}1/2^{+}$ is that the determination of their properties is difficult due to the presence of large and complicated backgrounds. The fact that in many cases the reflections (and/or interferences) due to competing processes distort important domains of the decay angular distributions prevents the extraction of quantities such as density matrix elements, hyperon polarization and transversity amplitudes. These circumstances explain why we restrict the discussion to the total and differential cross sections.

In table 10 we have summarized the cross sections for the various 2^{+} processes studied in this paper. For completeness we have added the available information on the reactions with $A_2(1300)$ production. For the reaction $K^-p \rightarrow A_2(1300)\Lambda$ we quote the forward and backward cross sections obtained in ref. [20] using the Dalitz array technique. In the forward

direction this method gives results in excellent agreement with those calculated using a partial wave analysis [3]. In the backward region ($0.0 < u' < 1.5 \text{ GeV}^2$) the measurement performed in ref. [21] is again consistent with the one based on the Dalitz array.

For the reaction $K^- p \rightarrow A_2(1300)\Sigma^0$ we quote for the backward cross section that obtained from the value given in ref. [21] for the process $K^- p \rightarrow \Sigma^- A_2(1300)$ and the assumption of $I = 1/2$ exchange dominance [22]. The forward cross section was obtained using this value and the total cross section obtained in sect. 3.6.

For further reference (sect. 5.4, 5.5) we have included the cross sections obtained for the corresponding vector meson reactions (refs [1(b)] and [1(j)]). For the process $K^- p \rightarrow \omega \Sigma^0$ we have used the relation $\sigma(K^- p \rightarrow \omega \Sigma^0) = 1/2 \sigma(K^- n \rightarrow \omega \Sigma^-)$ and have interpolated to 4.2 GeV/c the values measured at 3.0 GeV/c [23] and 4.93 GeV/c [19].

5.1 Branching ratios of the $f^0(1270)$ and $f'(1515)$

Within large errors there is agreement in the values of the $K^- p \rightarrow f^0(1270)\Lambda$ cross section determined in sect. 3.3 and 3.5 separately from the decay modes $f^0 \rightarrow \pi^+ \pi^-$ and $f^0 \rightarrow K^+ K^-$ after making use of the $f^0(1270)$ branching ratios quoted by the PDG [4].

To determine directly from our data the ratio between these two $f^0(1270)$ decay modes, we make use of the fact that the $f^0 \rightarrow \pi^+ \pi^-$ decay in backward f^0 production is not affected by complicated background effects. Indeed, in the production sector $-1.0 < \cos \theta_{p-\Lambda} < -0.5$ the reflections affecting the f^0 mass regions are small and structureless apart from some $\bar{\Sigma}^-(1385)$ background (fig. 27(d)). A fit, displayed in fig. 40(a), to this effective mass distribution using the form discussed in sect. 4.3 gives 1540 ± 100 $f^0(1270)$ events. The $K^+ K^-$ effective mass distribution in the same backward production sector is shown in fig. 40(b); the number of events in the region $1.14 < M(K^+ K^-) < 1.40 \text{ GeV}$ over the background is estimated to be < 30 . From these values we obtain the following upper limit

$$\frac{\Gamma(f \rightarrow K\bar{K})}{\Gamma(f \rightarrow \pi\pi)} < 0.03 \text{ (95\% CL)}$$

in agreement with the value 0.039 ± 0.005 given in ref. [4].

To calculate the ratio between the $\pi\pi$ and $K\bar{K}$ decay modes of the $f'(1515)$ we use the fact that the $f'(1515)$ is preferentially produced in the angular sector $0.5 < \cos\theta_{p-\Lambda} < 1.0$. The K^+K^- and $\pi^+\pi^-$ effective mass distributions in this angular region are shown in fig. 41. To reduce the background in the $\pi^+\pi^-$ distribution we selected events in the forward decay hemisphere of the $\pi^+\pi^-$ system (fig. 27(a)). We fitted these distributions following the methods discussed in sects 4.3 and 4.5. The number of $f' \rightarrow K^+K^-$ events obtained in this way was 580 ± 80 . The number of events in the region $M_{f'} - \Gamma_{f'} < M(\pi^+\pi^-) < M_{f'} + \Gamma_{f'}$ over the curve of fig. 41(a) was estimated to be 8. After correcting for the selection on the decay angle and slightly different events/ μb equivalent for the two reactions, we obtain the following upper limit:

$$\frac{\Gamma(f' \rightarrow \pi\pi)}{\Gamma(f' \rightarrow K\bar{K})} < 0.06 \text{ (95\% CL)} .$$

In a previous analysis using the $f' \rightarrow K_s^0 K_s^0$ decay mode in the same experiment, the ACNO Collaboration [2] found a value < 0.045 also at the 95% CL.

5.2 Zweig rule comparison

Following the approach suggested by Lipkin [17] and used in ref. [2], it is possible to determine the parameter θ_T , which measures the deviation from the ideal mixing angle, from the ratio of the backward cross sections

$$\tan^2 \theta_T = \frac{\sigma(K^- p \rightarrow \Lambda f')_B}{\sigma(K^- p \rightarrow \Lambda f)_B} .$$

Using the values calculated in sect. 4 we find

$$\tan^2 \theta_T < 0.02 \text{ (95\% CL)}$$

in good agreement with the value of ref. [2].

A similar ratio can be calculated for the vector meson reactions

$$\tan^2 \theta_V = \frac{\sigma(K^- p \rightarrow \Lambda \phi)_B}{\sigma(K^- p \rightarrow \Lambda \omega)_B}.$$

We obtained the value

$$\tan^2 \theta_V = 0.014 \pm 0.004,$$

which is similar to the one given for the 2^+ nonet.

5.3 Forward production

SU(3) together with factorization and absence of exotics predicts the following relations between amplitudes for the 2^+ meson reactions studied here

$$A(K^- p \rightarrow f^0 Y) = A(K^- p \rightarrow A_2^0 Y),$$

$$A(K^- p \rightarrow f' Y) = A(\pi^- p \rightarrow K^0(1420) Y),$$

where

$$Y = \Lambda, \Sigma^0 \text{ or } \Sigma^0(1385).$$

The similar relations for vector meson reactions have been extensively investigated in this energy range (refs [1(b)] and [1(j)]) and shown to be well satisfied by the data.

The comparison between the f^0 and A_2^0 cross sections can be made using the integrated value of the $A_2^0 \Lambda$ cross section for $|t| < 1.0 \text{ GeV}^2$ obtained in a partial wave analysis of the 3π system in the reaction $K^- p \rightarrow \pi^+ \pi^- \pi^0 \Lambda$ [3]. After correcting for unseen decay modes the value $\sigma(K^- p \rightarrow A_2^0 \Lambda) = 22.3 \pm 2.2 \text{ } \mu\text{b}$ was obtained. The integrated cross section for $|t| < 1 \text{ GeV}^2$ for the f^0 process was measured to be $\sigma(K^- p \rightarrow f^0 \Lambda) = 28 \pm 3 \text{ } \mu\text{b}$ which is consistent with the value quoted above.

The comparison between the f' and $K^0(1420)$ reactions is presented in figs 42 and 43. Within the large errors the two cross sections have comparable size.

If in addition to SU(3) one assumes that Regge poles are exchange degenerate, one obtains the following relation between f^0 and f' production

$$\sigma(f'\Lambda) = 2\sigma(f^0\Lambda),$$

$$\sigma(f'\Sigma^0) = 2\sigma(f^0\Sigma^0).$$

As the data presented in figs 42 and 43 show, the "real" reactions $K^-p \rightarrow f^0(\Lambda, \Sigma^0)$ have much larger cross sections than the "rotating" ones $K^-p \rightarrow f'(\Lambda, \Sigma^0)$.

The shapes of the differential cross sections $d\sigma/dt'$ of the "real" and "rotating" reactions (for Σ and Λ) are also different. In models of exchange degenerate Regge poles and absorptive cuts [24] the t dependence of the real and rotating reactions is qualitatively understood as follows. The observation $\sigma(\text{real}) > \sigma(\text{rot})$ implies that the cut contribution is imaginary. Then, the destructive effect of the cut on the rotating amplitude is greatest at small t and $\sigma(\text{real})/\sigma(\text{rot})$ becomes larger at small t .

The relative success of SU(3) (or quark additivity) in relating different vector and tensor meson production reactions and the failure of exchange degeneracy in this energy range are some of the most relevant features of hypercharge exchange processes.

Apart from the SU(3) relations, which hold approximately for 1^- and 2^+ meson production, the two sets of processes seem to have different dynamical properties. In particular, the ratio of the forward cross sections for Σ^0 and Λ changes for the 1^- and 2^+ mesons. More explicitly we find

$$\frac{\sigma_F(K^0(890)\Sigma^0)}{\sigma_F(K^0(890)\Lambda)} \sim 2 \frac{\sigma_F(\rho^0\Sigma^0)}{\sigma_F(\rho^0\Lambda)} \sim \frac{1}{2},$$

whereas

$$\frac{\sigma_F(K^0(1420)\Sigma^0)}{\sigma_F(K^0(1420)\Lambda)} \sim \frac{1}{2} \frac{\sigma_F(f^0\Sigma^0)}{\sigma_F(f^0\Lambda)} \sim \frac{1}{4}.$$

5.4 Finite mass sum rules (FMSR)

In the context of FMSR and triple Regge ideas [24] one expects that the high mass part of a spectrum should be enhanced in the backward direction. This is due to the fact that in the triple Regge model $d^2\sigma/dtdm^2 \sim (m^2)^{-2\alpha(t)}$, $\alpha(t)$ being the exchanged Regge trajectory coupled to the baryon vertex. As t becomes more negative, (backward production), $\alpha(t)$ becomes smaller and the higher mass part of the spectrum is favoured.

These considerations imply that the ratios $K(1420)/K(890)$, f/ρ , A_2/ω should be larger for backward production than for forward production. With the exception of the $\Sigma^0 f/\Sigma^0 \rho$ ratio, the values given in table 10 are consistent with this prediction. In fact, there is an ambiguity whether one should compare f/ρ , A_2/ω (same G parity) or f/ω , A_2/ρ (same isospin). The latter works best here.

Another consequence of FMSR is that the ratio of unnatural versus natural parity exchanges (K/K^*) should increase with the mass. In principle, we can roughly check this by inspecting the values of ρ_{00} for the ρ and f reactions. The average values of ρ_{00} obtained in the Dalitz plot analyses described in sect. 3 ($\Lambda\rho : \rho_{00}^* = 0.166 \pm 0.010$; $\Lambda f : \rho_{00} = 0.257 \pm 0.020$; $\Sigma^0\rho : \rho_{00} = 0.093 \pm 0.020$; $\Sigma^0 f : \rho_{00} = 0.179 \pm 0.040$) are consistent with this prediction. The mass dependence of the ratio of unnatural versus natural parity exchange contributions given by FMSR also implies that the Σ^0/Λ cross section ratio should decrease with the resonance mass. This is because $\Sigma^0/\Lambda = 3 \left(\frac{F/D-1}{3F/D+1} \right)^2$ and for K^* exchange $F/D \approx -3$ and thus, $\Sigma/\Lambda = 0.75$ whereas for K exchange $F/D \approx 0.45$ and $\Sigma/\Lambda \approx 0.15$ [24]. The values of the forward cross sections for the reactions with ρ , f , ϕ and f' are consistent with this prescription.

5.5 Backward production

Under the assumption that backward peaks in the processes $K^- p \rightarrow M + (\Lambda, \Sigma^0)$, where M is the singlet component of a $SU(3)$ nonet, are dominated by baryon exchange, it is possible to extract the ratio of coupling constants $g_{\Sigma NK}^2/g_{\Lambda NK}^2$. An investigation following this line has already been made using data on the reactions $K^- p \rightarrow \Lambda\omega$ and $K^- n \rightarrow \Sigma^-\omega$ at 3 GeV/c [23]; the ratio of the backward cross sections

$$\frac{\sigma_B(K^- n \rightarrow \Sigma^- \omega)}{\sigma_B(K^- p \rightarrow \Lambda \omega)}$$

was used as an estimation of the ratio

$$R = g_{\Sigma NK}^2 / g_{\Lambda NK}^2 .$$

According to SU(3) symmetry, the ratio R can be expressed in terms of the fractional contribution of the antisymmetric BBP coupling

$$R = \frac{6(1 - 2\alpha)^2}{(1 + 2\alpha)^2}, \quad \alpha = F/(F+D) .$$

The SU(6) prediction $\alpha = 0.4$ leads to an expected value $R \approx 0.08$ which was claimed to be in disagreement with the estimated value $R = 0.6 \pm 0.25$.

We have made a similar analysis using the ratio

$$\frac{2 \frac{d\sigma}{du'} (K^- p \rightarrow \Sigma^0 f)}{\frac{d\sigma}{du'} (K^- p \rightarrow \Lambda f)}$$

as a function of u' . The results of this analysis are given in table 11 and show a dependence of R with u' . The discrepancy with the SU(6) prediction seems to be larger near $u' \approx 0$.

It is interesting to notice that using the values given in table 10 for the backward cross sections, we estimate $R = 0.32 \pm 0.13$ from the ω reactions and $R = 0.33 \pm 0.07$ from the f^0 reactions. The good agreement between the two determinations argues in favour of the factorization hypothesis for the exchanged Regge trajectory.

6. CONCLUSIONS

We have presented an analysis of the hypercharge exchange reactions $\pi^- p \rightarrow K^0(1420)(\Lambda, \Sigma^0)$, $K^- p \rightarrow f^0(1270)(\Lambda, \Sigma^0)$ and $K^- p \rightarrow f'(1515)(\Lambda, \Sigma^0)$ at 3.95 GeV/c incident π^- momentum and 4.2 GeV/c incident K^- momentum.

The statistical sensitivities of the two experiments are ~ 90 and ~ 128 events/ μb respectively.

The production of 2^+ mesons in hypercharge exchange processes at our energy is difficult to study in detail due to the large and complex background present, which make polarization measurements unrealistic.

These background problems are of much easier solution for the determination of the total and differential cross sections on which we have based the discussion of the data.

The dynamical properties of 2^+ meson production have features which are common to those of the corresponding 1^- meson reactions. Thus, the relations derived from SU(3) and factorization hold for both nonets while the predictions of EXD are not fulfilled. The deviations from ideal mixing are similar for the two nonets and consistent values of the ratio of coupling constants $g_{\Sigma\text{NK}}^2/g_{\Lambda\text{NK}}^2$ are obtained when reactions from the two nonets are used. Finally, some simple predictions based on Finite Mass Sum Rules and triple Regges ideas are consistent with the data for 1^- and 2^+ processes.

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TABLE CAPTIONS

- Table 1 Results of the fit to the $M^2(K^+\pi^-)$ vs $M^2(\Lambda\pi^-)$ diagram from the reaction $\pi^-p \rightarrow \Lambda K^+\pi^-$.
- Table 2 Results of the fit to the diagram $M(\pi^+\pi^-)$ vs $M(\Lambda\pi^+)$ for the reaction $K^-p \rightarrow \Lambda\pi^+\pi^-$.
- Table 3 Results of the fit to the diagram $M(\pi^+\pi^-)$ vs $M(\Sigma^0\pi^+)$ for the reaction $K^-p \rightarrow \Sigma^0\pi^+\pi^-$.
- Table 4 Differential cross section for the process $\pi^-p \rightarrow K^0(1420)\Lambda$.
- Table 5 Differential cross section for the process $\pi^-p \rightarrow K^0(1420)\Sigma^0$.
- Table 6 Differential cross section for the process $K^-p \rightarrow f^0\Lambda$.
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- Table 9 Differential cross section for the process $K^-p \rightarrow f'\Sigma^0$.
- Table 10 Summary of cross sections (total, forward and backward) for the reactions studied in this paper and for the similar processes with production of 1^- mesons.
- Table 11 Ratio of the cross sections $2 d\sigma/du'(K^-p \rightarrow f\Sigma^0) / d\sigma/du'(K^-p \rightarrow f\Lambda)$ as a function of u' .

TABLE 1

Parameters (fractions, ρ_{mm})	$\pi^- p \rightarrow \Lambda K^+ \pi^-$
%[K(890)]	50.3 $\pm$ 1.0
%[K(1420)]	11.0 $\pm$ 1.0
%[$\Sigma(1385)$]	4.4 $\pm$ 0.5
%[N(1700)]	4.7 $\pm$ 0.8
ρ_{00} [K(890)]	0.27 $\pm$ 0.02
ρ_{00} [K(1420)]	0.08 $\pm$ 0.06
ρ_{11} [K(1420)]	0.24 $\pm$ 0.03
$\rho_{\frac{3}{2} \frac{3}{2}}$ [$\Sigma(1385)$]	0.19 $\pm$ 0.06

TABLE 2

Resonance	$K^- p \rightarrow \Lambda \pi^+ \pi^-$ fraction
$[\epsilon(700)]$	0.152 ± 0.010
$[\rho(770)]$	0.178 ± 0.008
$[\epsilon'(1300)]$	0.008 ± 0.008
$[f(1270)]$	0.133 ± 0.011
$[g(1680)]$	0.042 ± 0.013
$[\Sigma^+(1385)]$	0.202 ± 0.007
$[\Sigma^+(1700)]$	0.165 ± 0.013
$[\Sigma^+(2030)]$	0.039 ± 0.013
$[\Sigma^-(1385)]$	0.030 ± 0.003
$[\Sigma^-(1700)]$	0.032 ± 0.009
$\rho_{00}[f(1270)]$	0.257 ± 0.020
$\rho_{11}[f(1270)]$	0.181 ± 0.009
$\rho_{22}[f(1270)]$	0.191
$\rho_{00}[\rho(770)]$	0.166 ± 0.010
$\rho_{11}[\rho(770)]$	0.417

TABLE 3

Resonance	$K^- p \rightarrow \Sigma^0 \pi^+ \pi^-$ fraction
$[\epsilon(700)]$	0.139 ± 0.010
$[\rho(770)]$	0.211 ± 0.010
$[\epsilon'(1300)]$	0.008 ± 0.010
$[f(1270)]$	0.115 ± 0.011
$[g(1680)]$	0.039 ± 0.008
$[\Sigma^+(1385)]$	0.030 ± 0.005
$[\Sigma^+(1460)]$	0.032 ± 0.005
$[\Sigma^+(1660)]$	0.136 ± 0.012
$[\Sigma^+(1915)]$	0.031 ± 0.006
$[\Sigma^-(1385)]$	0.004 ± 0.002
$[\Sigma^-(1460)]$	0.007 ± 0.002
$[\Sigma^-(1660)]$	0.072 ± 0.042
$[\Sigma^-(1915)]$	0.003 ± 0.003
$\rho_{00}[f(1270)]$	0.179 ± 0.040
$\rho_{11}[f(1270)]$	0.248 ± 0.023
$\rho_{22}[f(1270)]$	0.162
$\rho_{00}[\rho(770)]$	0.093 ± 0.020
$\rho_{11}[\rho(770)]$	0.453

TABLE 4

$t'(\text{GeV}^2)$	$d\sigma/dt'(\mu\text{b}/\text{GeV}^2)$
0.00 - 0.05	64 ± 15
0.05 - 0.10	34 ± 14
0.10 - 0.20	29 ± 8
0.20 - 0.30	14 ± 6
0.30 - 0.60	15 ± 4
0.60 - 1.00	18 ± 4
1.00 - 1.50	9 ± 2

TABLE 5

$t'(\text{GeV}^2)$	$d\sigma/dt'(\mu\text{b}/\text{GeV}^2)$
0.0 - 0.5	5.1 ± 1.5
0.5 - 1.0	5.4 ± 2.2
1.0 - 1.5	2.7 ± 1.2

TABLE 6

$t'(\text{GeV}^2)$	$d\sigma/dt'(\mu\text{b}/\text{GeV}^2)$
0.0 - 0.05	45 ± 11
0.05 - 0.1	48 ± 13
0.1 - 0.2	51 ± 9
0.2 - 0.3	56 ± 8
0.3 - 0.5	40 ± 6
0.5 - 0.7	21 ± 4
0.7 - 1.0	11 ± 2
1.0 - 1.5	8 ± 1.4
1.5 - 2.0	5 ± 1.3
$u'(\text{GeV}^2)$	$d\sigma/du'(\mu\text{b}/\text{GeV}^2)$
0.0 - 0.1	26 ± 5
0.1 - 0.2	47 ± 8
0.2 - 0.3	42 ± 7
0.3 - 0.5	28 ± 4
0.5 - 0.7	26 ± 4
0.7 - 1.0	25 ± 3
1.0 - 1.5	15 ± 2
1.5 - 2.0	4 ± 1

TABLE 7

$t'(\text{GeV}^2)$	$d\sigma/dt'(\mu\text{b}/\text{GeV}^2)$
0.00 - 0.05	17 ± 7
0.05 - 0.1	36 ± 6
0.1 - 0.2	24 ± 4
0.2 - 0.3	37 ± 5
0.3 - 0.5	12 ± 4
0.5 - 0.7	20 ± 4
0.7 - 1.0	6.5 ± 2.4

$u'(\text{GeV}^2)$	$d\sigma/du'(\mu\text{b}/\text{GeV}^2)$
0.0 - 0.2	13 ± 3
0.2 - 0.5	4 ± 1.3
0.5 - 1.0	2 ± 0.8
1.0 - 1.5	2.4 ± 0.8

TABLE 8

$t'(\text{GeV}^2)$	$d\sigma/dt'(\mu\text{b}/\text{GeV}^2)$
0.0 - 0.2	25 ± 5
0.2 - 0.4	18 ± 4
0.4 - 0.8	10 ± 2
0.8 - 1.5	4 ± 1

TABLE 9

$t'(\text{GeV}^2)$	$d\sigma/dt'(\mu\text{b}/\text{GeV}^2)$
0.0 - 0.2	5.6 ± 1.7
0.2 - 0.4	4.8 ± 1.7
0.4 - 0.8	3.1 ± 0.8
0.8 - 1.5	1.4 ± 0.5

TABLE 10

Reaction	$\sigma(\mu\text{b})$	$\sigma_F(\mu\text{b})$	$\sigma_B(\mu\text{b})$
$\pi^- p \rightarrow K^0(1420)\Lambda$	27 ± 3	24.5 ± 3.0	2.5 ± 1.1
$K^- p \rightarrow f^0(1270)\Lambda$	77 ± 6	37.7 ± 3.8	39.3 ± 4.0
$K^- p \rightarrow A_2(1300)\Lambda$	36 ± 15	28 ± 6.0	19.0 ± 5.0
$K^- p \rightarrow f'(1515)\Lambda$	19 ± 3	19 ± 3.0	< 0.8
$\pi^- p \rightarrow K^0(1420)\Sigma^0$	10 ± 2	6.3 ± 1.5	3.7 ± 1.1
$K^- p \rightarrow f^0(1270)\Sigma^0$	26 ± 3	19.5 ± 2.7	6.5 ± 1.3
$K^- p \rightarrow A_2(1300)\Sigma^0$	10 ± 9	6 ± 9	4 ± 1
$K^- p \rightarrow f'(1515)\Sigma^0$	4.3 ± 0.8	4.3 ± 0.8	< 0.3
$\pi^- p \rightarrow K^0(890)\Lambda$	62 ± 3	57 ± 3	5.0 ± 0.6
$K^- p \rightarrow \omega\Lambda$	91 ± 8	60.0 ± 5.3	31.0 ± 2.8
$K^- p \rightarrow \rho\Lambda$	82 ± 8	57.0 ± 5.6	25.0 ± 2.5
$K^- p \rightarrow \phi\Lambda$	66 ± 4	65.5 ± 4	0.5 ± 0.15
$\pi^- p \rightarrow K^0(890)\Sigma^0$	32 ± 2	28.8 ± 2.0	3.2 ± 0.4
$K^- p \rightarrow \omega\Sigma^0$	22 ± 5	17 ± 5	5 ± 2
$K^- p \rightarrow \rho\Sigma^0$	30 ± 3	19 ± 2	11.0 ± 1.2
$K^- p \rightarrow \phi\Sigma^0$	34 ± 3	33.8 ± 3	0.2 ± 0.1

TABLE 11

u'	$R = 2\sigma(\Sigma^0 f)/\sigma(\Lambda f)$
0.0 - 0.2	0.70 ± 0.16
0.2 - 0.5	0.26 ± 0.08
0.5 - 1.0	0.16 ± 0.06
1.0 - 1.5	0.32 ± 0.10

FIGURE CAPTIONS

- Fig. 1 $M^2(K^+\pi^-)$ vs $M^2(\Lambda\pi^-)$ Dalitz plot for reaction $\pi^- \rightarrow \Lambda K^+\pi^-$.
- Fig. 2 (a)-(c) $K^+\pi^-$, $\Lambda\pi^-$ and ΛK^+ effective mass distributions for reaction $\pi^- p \rightarrow \Lambda K^+\pi^-$. The curves are the results of the Dalitz plot fit discussed in the text.
- Fig. 3 $M^2(K^+\pi^-)$ vs $M^2(\Sigma^0\pi^-)$ Dalitz plot for reaction $\pi^- p \rightarrow \Sigma^0 K^+\pi^-$.
- Fig. 4 (a)-(c) $K^+\pi^-$, $\Sigma^0\pi^-$ and $\Sigma^0 K^+$ effective mass distributions for reaction $\pi^- p \rightarrow \Sigma^0 K^+\pi^-$. The curve in (a) is the result of the mass fit discussed in the text.
- Fig. 5 $M^2(\pi^+\pi^-)$ vs $M^2(\Lambda\pi^+)$ Dalitz plot for reaction $K^- p \rightarrow \Lambda\pi^+\pi^-$.
- Fig. 6 (a)-(c) $\pi^+\pi^-$, $\Lambda\pi^+$ and $\Lambda\pi^-$ effective mass distributions for reaction $K^- p \rightarrow \Lambda\pi^+\pi^-$. The curves are the results of the Dalitz plot fit discussed in the text.
- Fig. 7 (a) and (b) $\Lambda\pi^+$ and $\Lambda\pi^-$ effective mass distributions for events with $1.14 < M(\pi^+\pi^-) < 1.40$ GeV.
- Fig. 8 s channel helicity polar decay distribution of the $\pi^+\pi^-$ system for events with $1.14 < M(\pi^+\pi^-) < 1.40$ GeV in the reaction $K^- p \rightarrow \Lambda\pi^+\pi^-$. The curve is the result of the fit discussed in the text.
- Fig. 9 Results of the best fit to the $M(\pi^+\pi^-)$ - $M(\Lambda\pi^+)$ distribution. For each cell the experimental number of events, the theoretical value, the error squared on the number of experimental events and the partial χ^2 are presented.
- Fig. 10 $M^2(\pi^+\pi^-)$ vs $M^2(\Sigma^0\pi^+)$ Dalitz Plot for reaction $K^- p \rightarrow \Sigma^0\pi^+\pi^-$.
- Fig. 11 (a)-(c) $\pi^+\pi^-$, $\Sigma^0\pi^+$ and $\Sigma^0\pi^-$ effective mass distributions for reaction $K^- p \rightarrow \Sigma^0\pi^+\pi^-$. The curves are the results of the Dalitz plot fit discussed in the text.

FIGURE CAPTIONS (Cont'd)

- Fig. 12 (a) and (b) $\Sigma^0\pi^+$ and $\Sigma^0\pi^-$ effective mass distributions for reaction $K^-p \rightarrow \Sigma^0\pi^+\pi^-$.
- Fig. 13 (a) and (b) $\Sigma^0\pi^+$ and $\Sigma^0\pi^-$ effective mass distributions for events with $1.14 < M(\pi^+\pi^-) < 1.40$ GeV.
- Fig. 14 s channel helicity polar decay distribution of the $\pi^+\pi^-$ system for events with $1.14 < M(\pi^+\pi^-) < 1.40$ GeV in the reaction $K^-p \rightarrow \Sigma^0\pi^+\pi^-$.
- Fig. 15 Results of the best fit to the $M(\pi^+\pi^-)$ - $M(\Sigma^0\pi^+)$ distribution. For each cell the experimental number of events, the theoretical value, the error squared on the number of experimental events and the partial χ^2 are presented.
- Fig. 16 $M^2(K^+K^-)$ vs $M^2(\Lambda K^-)$ Dalitz plot for reaction $K^-p \rightarrow \Lambda K^+K^-$.
- Fig. 17 (a)-(c) K^+K^- , ΛK^+ and ΛK^- effective mass distributions for reaction $K^-p \rightarrow \Lambda K^+K^-$. The curve in (a) is the result of the mass fit described in the text.
- Fig. 18 $M^2(K^+K^-)$ vs $M^2(\Sigma^0 K^-)$ Dalitz plot for reaction $K^-p \rightarrow \Sigma^0 K^+K^-$.
- Fig. 19 (a)-(c) K^+K^- , $\Sigma^0 K^+$ and $\Sigma^0 K^-$ effective mass distribution for reaction $K^-p \rightarrow \Sigma^0 K^+K^-$. The curve in (a) is the result of the mass fit described in the text.
- Fig. 20 $M^2(K^+\pi^-)$ vs $t(p,\Lambda)$ distribution for reaction $\pi^-p \rightarrow \Lambda K^+\pi^-$.
- Fig. 21 Differential cross section ($d\sigma/dt'$) for reactions $\pi^-p \rightarrow K^0(1420)\Lambda$ and $\pi^-p \rightarrow K^0(890)\Lambda$.
- Fig. 22 $M^2(K^+\pi^-)$ vs $t(p,\Sigma^0)$ distribution for reaction $\pi^-p \rightarrow \Sigma^0 K^+\pi^-$.
- Fig. 23 Differential cross section ($d\sigma/dt'$) for reactions $\pi^-p \rightarrow K^0(1420)\Sigma^0$ and $\pi^-p \rightarrow K^0(890)\Sigma^0$.

FIGURE CAPTIONS (Cont'd)

- Fig. 24 $M^2(\pi^+\pi^-)$ vs $t(p,\Lambda)$ distribution for reaction $K^-p \rightarrow \Lambda\pi^+\pi^-$.
- Fig. 25 $\cos\theta_{p-\Lambda}$ production distribution for events with $1.14 < M(\pi^+\pi^-) < 1.40$ GeV in the reaction $K^-p \rightarrow \Lambda\pi^+\pi^-$.
- Fig. 26 (a)-(d) $\pi^+\pi^-$ effective mass distributions for events in the production sectors $0.5 < \cos\theta_{p-\Lambda} < 1.0$, $0.0 < \cos\theta_{p-\Lambda} < 0.5$, $-0.5 < \cos\theta_{p-\Lambda} < -0.0$ and $-1.0 < \cos\theta_{p-\Lambda} < -0.5$ (reaction $K^-p \rightarrow \Lambda\pi^+\pi^-$).
- Fig. 27 (a)-(d) $\cos\theta_{\pi\pi}^{SH}$ (cosine of the s channel helicity polar decay angle) decay distributions for events in the f^0 mass band $1.14 < M(\pi^+\pi^-) < 1.40$ GeV and in the production sectors $0.5 < \cos\theta_{p-\Lambda} < 1.0$, $0.0 < \cos\theta_{p-\Lambda} < 0.5$, $-0.5 < \cos\theta_{p-\Lambda} < 0.0$ and $-1.0 < \cos\theta_{p-\Lambda} < -0.5$ (reaction $K^-p \rightarrow \Lambda\pi^+\pi^-$).
- Fig. 28 (a) and (b) differential cross sections $d\sigma/dt'$ and $d\sigma/du'$ for reactions $K^-p \rightarrow f^0(1270)\Lambda$ and $K^-p \rightarrow \omega\Lambda$.
- Fig. 29 $M^2(\pi^+\pi^-)$ vs $t(p,\Sigma^0)$ distribution for reaction $K^-p \rightarrow \Sigma^0\pi^+\pi^-$.
- Fig. 30 $\cos\theta_{p-\Sigma^0}$ production distribution for events with $1.14 < M(\pi^+\pi^-) < 1.40$ GeV in the reaction $K^-p \rightarrow \Sigma^0\pi^+\pi^-$.
- Fig. 31 (a) and (b) $\pi^+\pi^-$ effective mass distributions for events in the production sectors $0.0 < \cos\theta_{p-\Sigma^0} < 1.0$ and $-1.0 < \cos\theta_{p-\Sigma^0} < 0.0$ (reaction $K^-p \rightarrow \Sigma^0\pi^+\pi^-$).
- Fig. 32 (a) and (b) $\cos\theta_{\pi\pi}^{SH}$ (cosine of the s channel helicity polar decay angle) decay distributions for events in the f^0 mass band $1.14 < M(\pi^+\pi^-) < 1.40$ GeV and in the production sectors $0.0 < \cos\theta_{p-\Sigma^0} < 1.0$ and $-1.0 < \cos\theta_{p-\Sigma^0} < 0.0$ (reaction $K^-p \rightarrow \Sigma^0\pi^+\pi^-$).
- Fig. 33 Differential cross sections $d\sigma/dt'$ and $d\sigma/du'$ for the reaction $K^-p \rightarrow f^0(1270)\Sigma^0$.

FIGURE CAPTIONS Cont'd

- Fig. 34 $M^2(K^+K^-)$ vs $t(p,\Lambda)$ distribution for reaction $K^-p \rightarrow \Lambda K^+K^-$.
- Fig. 35 Differential cross sections for reactions $K^-p \rightarrow f'\Lambda$ and $K^-p \rightarrow \phi\Lambda$.
- Fig. 36 K^+K^- effective mass distribution for events in the backward hemisphere $-1.0 < \cos\theta_{p-\Lambda} < 0.0$ for reaction $K^-p \rightarrow \Lambda K^+K^-$.
- Fig. 37 $M^2(K^+K^-)$ vs $t(p,\Sigma^0)$ distribution for reaction $K^-p \rightarrow \Sigma^0 K^+K^-$.
- Fig. 38 Differential cross sections for reactions $K^-p \rightarrow f'\Sigma^0$ and $K^-p \rightarrow \phi\Sigma^0$.
- Fig. 39 K^+K^- effective mass distribution for events in the backward hemisphere $(-1.0 < \cos\theta_{p-\Lambda} < 0.0)$ for reaction $K^-p \rightarrow \Sigma^0 K^+K^-$.
- Fig. 40 (a) and (b) $\pi^+\pi^-$ and K^+K^- effective mass distributions for the reactions $K^-p \rightarrow \Lambda\pi^+\pi^-$ and $K^-p \rightarrow \Lambda K^+K^-$ after imposing the selection $-1.0 < \cos\theta_{p-\Lambda} < -0.5$. The curve in (a) is the result of the fit described in the text. The straight line in (b) is a hand drawn estimation of the background.
- Fig. 41 (a) and (b) $\pi^+\pi^-$ and K^+K^- effective mass distributions for the reactions $K^-p \rightarrow \Lambda\pi^+\pi^-$ and $K^-p \rightarrow \Lambda K^+K^-$ after imposing the selection $0.5 < \cos\theta_{p-\Lambda} < 1.0$ (in (a) and (b)) and $0.0 < \cos\theta^{S-H} < 1.0$ (in (a)), (where θ^{S-H} is the polar helicity decay angle of the $\pi^+\pi^-(K^+K^-)$ system in the s channel frame). The curves are the result of the fits described in the text.
- Fig. 42 Differential cross sections for the processes $K^-p \rightarrow f^0\Lambda(\phi)$, $\pi^-p \rightarrow K^0(1420)\Lambda(\phi)$ and $K^-p \rightarrow f'\Lambda(\phi)$.
- Fig. 43 Differential cross sections for the processes $K^-p \rightarrow f^0\Sigma^0(\phi)$, $\pi^-p \rightarrow K^0(1420)\Sigma^0(\phi)$ and $K^-p \rightarrow f'\Sigma^0(\phi)$.

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