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EXOTIC EXCHANGE PROCESSES IN K^-p AND π^-p INTERACTIONS AT 4 GeV/c

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ABSTRACT

Exotic exchange processes observed in K^-p and π^-p scattering in the neighbourhood of 4 GeV/c are analysed in terms of standard models. Some new data on π^-p induced processes are presented and used in the analysis. Regge-Regge cut predictions are found to be smaller than the data up to these energies. Baryonium exchange models are shown to be indistinguishable from Regge cut models as regards their phenomenological predictions. The double scattering quark model of Bialas and Zalewski is compatible with data on the exotic exchange production of Σ and $Y^*(1385)$, but fails for Ξ and $\Xi^*(1530)$ production. Modifications of this model are discussed.

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1. INTRODUCTION

Processes with exchange of exotic quantum numbers (non- $q\bar{q}$ or qqq) provide one of the crucial pieces of evidence for the correctness of Regge pole exchange and constituent quark model ideas. That is, one finds a convincing correlation between the absence of quark model exotics in the hadronic spectrum and the suppression of corresponding exotic peripheral exchange. Consider the processes $K^- p \rightarrow \pi^- \Sigma^+$ and $K^- p \rightarrow \pi^+ \Sigma^-$. From an s-channel resonance point of view there is no reason to expect much difference between them (both contain hyperon resonances) and, in fact, their cross sections at low energies are comparable. However, when one compares their respective t-channels ($K^- \pi^+ \rightarrow \bar{p} \Sigma^+$ and $K^- \pi^- \rightarrow \bar{p} \Sigma^-$) the twin assumptions of Regge pole dominance and absence of quark model exotics lead one to expect very different behaviours at high energy. Indeed by 4 GeV/c the exotic cross section ($K^- p \rightarrow \pi^+ \Sigma^-$) is already suppressed by a factor of ~ 200 [1]. There are several such examples.

As well as confirming the basic correctness of Regge pole ideas, exotic processes allow further insight into the strong interaction dynamics of peripheral collisions. The pattern of (small) exotic cross sections now observed provides a challenge to models of Regge-Regge cuts, quark rearrangement and possible baryonium Regge poles. Nicolescu [2] has presented a fairly comprehensive review of exotic exchange data with particular reference to the baryonium interpretation. Since then, more data have become available, particularly for resonance production by exotic exchange, and the evidence for production of baryonium states themselves has all but disappeared [3]. Evidence for Regge-Regge cut models and for baryonium exchange models must come primarily from energy dependent studies. This will be difficult to obtain because of the tiny rates involved. However, one can hope to use medium energy data, e.g. near 4 GeV/c, where cross sections are still measureable, to check predictions for the absolute magnitude and see at what energy one expects the models to become relevant, if at all. This will be a main aim of our paper.

In contrast to Regge-inspired models, the additive quark model says nothing about s-dependence, but relates families of reactions and suggests constraints on their spin structure. Bialas and Zalewski [4] have proposed

a variant of the additive quark model which can describe exotic exchange processes. The rich variety of information on families of processes now available at 4 GeV/c allows us to make significant tests of this model.

Our paper is organized as follows. In sect. 2 we present new data on the forward (exotic exchange) processes $\pi^- p \rightarrow K^+ \Sigma^-$, $K^{*+} \Sigma^-$, $K^{*+} Y^{*-}$ and $K^- p \rightarrow K^0 \Xi^0$, $\rho^+ Y^{*- (*)}$. In sect. 3, we collect together the evidence for exotic exchange in $\pi^- p$ and $K^- p$ scattering at 4 GeV/c and use isospin bounds to quantify the effects. Simple Regge-Regge cut estimates are compared with the data in sect. 4. This is followed in sect. 5 by a brief discussion of the competing baryonium exchange interpretation. In sect. 6, we consider the Bialas and Zalewski double scattering quark model and present modifications thereof which allow for known SU(6) breaking. Conclusions are drawn in sect. 7.

2. EXPERIMENTAL RESULTS

A large amount of data is available on two-body and quasi two-body reactions in the 4 GeV/c incident momentum region. They come mainly from the experiment of our collaboration on $\pi^- p$ interactions at 3.95 GeV/c and from the ACNO study of $K^- p$ interactions at 4.2 GeV/c. Both are high statistics experiments (~ 90 ev/ μ b and ~ 133 ev/ μ b respectively) performed in the CERN 2 m HBC and analysed with similar techniques.

In this paper we add, to the published data, information on the reactions (*)

$$\pi^- p \rightarrow K^+ \Sigma^- \quad (a)$$

$$\rightarrow K^{*+} \Sigma^- \quad (b)$$

$$\rightarrow K^{*+} Y^{*-} \quad (c)$$

at 3.95 GeV/c.

(*) Here and in the following we adopt the notation K^* , Y^* and Ξ^* for the $K^*(890)$, $Y^*(1385)$ and $\Xi^*(1530)$ resonances, respectively.

In previous publications we have given details of the general treatment of the data in the $\pi^- p$ experiment [5] and the procedures adopted to isolate quasi two-body reactions from a three or four-body final state [6]. For this reason, only a short description of the way in which results on reactions (a-c) were obtained will be given here.

In the π^- experiment we only studied final states in which the decay of at least one strange particle is observed. The reactions (a-c) were extracted from the final states

$$K^+ \Sigma^- \quad 403 \text{ events (570)} \quad (d)$$

$$K_s^0 \pi^+ \Sigma^- \quad 860 \text{ events (1284)} \quad (e)$$

$$\Lambda_s K^+ \pi^- \pi^0 \quad 5003 \text{ events (5400)} \quad (f)$$

where the subscript s indicates that the strange particle decay ($K^0 \rightarrow \pi^+ \pi^-$, $\Lambda \rightarrow p \pi^-$) is observed in the bubble chamber. Also indicated is the number of events for each final state and, in brackets, the number of events resulting from the weighting for detection losses due to strange particle decays occurring too close ($< 3 \text{ mm}$) or too far from the production vertex; a weight is also included for small projected angle ($< .07 \text{ rad}$) Σ^- decays.

Final states (d) and (e) have a 4-constraint kinematical fit and do not present serious ambiguity problems. The selection of the final state (f) is fully described in ref. [6].

The cross sections corrected for throughput efficiencies and unseen decay modes are

$$\sigma(\pi^- p \rightarrow K^+ \Sigma^-) = (9.6 \pm 1.0) \mu\text{b}$$

$$\sigma(\pi^- p \rightarrow K_s^0 \pi^+ \Sigma^-) = (46.1 \pm 3.5) \mu\text{b}$$

$$\sigma(\pi^- p \rightarrow K^+ \pi^- \pi^0 \Lambda) = (106 \pm 5) \mu\text{b}.$$

Turning now to reactions (a-c), we note that reaction (a) coincides with final state (d). The differential cross section for this reaction is shown in fig. 1. The cross section values for $|t'|(|u'|)^{(*)} < 1 \text{ GeV}^2$ are

(*) $t'(u')$ is defined as $t_{\text{max}} - t(u_{\text{max}} - u)$ where $t(u)$ is the square of the four-momentum transfer from the target (beam) to the outgoing Σ^- or γ^* .

$$\sigma_{|t'| < 1}(\bar{K}^+ \Sigma^-) = (.29 \pm .10) \mu\text{b} \quad \sigma_{|u'| < 1}(\bar{K}^+ \Sigma^-) = (7.5 \pm .7) \mu\text{b}.$$

The $\bar{K}^{*+} \Sigma^-$ reaction has been studied by means of the final state (e) ($\bar{K}_S^0 \pi^+ \Sigma^-$) where clear $\bar{K}^*$ production is present. Fig. 2 shows the $m^2(K\pi)$ vs t scatter plot: at the $\bar{K}^*$ mass accumulations of events both in the forward and backward directions are present. The total and partial cross sections, corrected for the undetected $\bar{K}^{*+}$ decay mode, are

$$\begin{aligned} \sigma(\pi^- p \rightarrow \bar{K}^{*+} \Sigma^-) &= (12.5 \pm 2.0) \mu\text{b} \\ \sigma_{|t'| < 1} &= (2.5 \pm .8) \mu\text{b} \\ \sigma_{|u'| < 1} &= (7.1 \pm 1.2) \mu\text{b}. \end{aligned}$$

Evidence for reaction (c) ($\bar{K}^{*+} Y^{*-}$) comes from the scatter plot $m(K^+ \pi^0)$ vs $m(\Lambda_S^- \pi^-)$ of final state (f) shown in fig. 3. A clear accumulation of events is seen in the overlapping region of the $\bar{K}^*$ and Y^* bands. Making use, as in ref. [6], of the slicing technique we have extracted the following total and partial cross sections corrected for the different decay modes of the $\bar{K}^*$ and the Y^*

$$\begin{aligned} \sigma(\pi^- p \rightarrow \bar{K}^{*+} Y^{*-}) &= (11 \pm 2) \mu\text{b} \\ \sigma_F &= (2.6 \pm 0.8) \mu\text{b} \\ \sigma_B &= (8 \pm 2) \mu\text{b}. \end{aligned}$$

where σ_F and σ_B refer to the full forward and backward production hemispheres respectively.

Having access to the ACNO data, we have also tried to compute the forward cross sections for the reactions $\bar{K}^- p \rightarrow \bar{K}^0 \Xi^0$ (g) and $\bar{K}^- p \rightarrow \rho^+ \Sigma^-$ (h) which will be used in the analysis presented in the next sections.

Reaction (g) has to be extracted (see ref. [7]) from the final state $\bar{K}_S^0 + \text{missing mass}$. There, a huge contribution from the "allowed" processes $\bar{K}^- p \rightarrow \bar{K}^0 n + \pi^0$'s is present. Therefore, we were only able to estimate the following upper limit: $\sigma(\bar{K}^- p \rightarrow \bar{K}^0 \Xi^0) < 8 \mu\text{b}$ for $|t'| < 1 \text{ GeV}^2$ (corrected for branching ratios and visibility factors). The cross in the backward production hemisphere was measured to be $5.5 \pm 1.0 \mu\text{b}$ [7].

To isolate reaction (h) we made use of the final state $\Sigma^- \pi^+ \pi^0$ already described in ref. [8]. A clear ρ^+ signal is obtained, for $|t'| < 1 \text{ GeV}^2$, by selecting events with $\cos\theta_H > 0$ (fig. 4). θ_H is the angle between the π^+ direction in the ρ^+ centre of mass with respect to the ρ^+ direction in the overall centre of mass. The selection $\cos\theta_H > 0$ removes from the low $\pi^+ \pi^0$ mass region the huge background due to the low mass Y^* 's present in the $\Sigma^- \pi^+$ mass spectrum. The curve in fig. 4 represents the fit to the data of a relativistic Breit-Wigner (with the ρ parameters fixed at the PDG values [9]) plus polynomial background. From this fit resulted the fully corrected cross section: $\sigma(K^- p \rightarrow \rho^+ \Sigma^-) = (2.5 \pm 1.0) \mu\text{b}$ for $|t'| < 1 \text{ GeV}^2$.

3. EXOTIC EXCHANGE AMPLITUDES

We shall consider exotic exchange processes of the types

$$0^- \frac{1}{2}^+ \rightarrow 0^- \frac{1}{2}^+ \quad (1)$$

$$0^- \frac{1}{2}^+ \rightarrow 0^- \frac{3}{2}^+ \quad (2)$$

$$0^- \frac{1}{2}^+ \rightarrow 1^- \frac{1}{2}^+ \quad (3)$$

$$0^- \frac{1}{2}^+ \rightarrow 1^- \frac{3}{2}^+ \quad (4)$$

initiated by $\bar{K}N$ and πN scattering. One may observe the exotic exchange amplitude $T_{3/2}$ directly or by interference with an "allowed" amplitude. For example, the t-channel isospin structure of the reactions $\bar{K}N \rightarrow \pi\Sigma$ is:

$$\begin{aligned} T(K^- p \rightarrow \pi^+ \Sigma^-) &= T_{3/2} \\ T(K^- p \rightarrow \pi^0 \Sigma^0) &= 2/3 T_{3/2} + 1/3 T_{1/2} \\ T(K^- p \rightarrow \pi^- \Sigma^+) &= 1/3 T_{3/2} + 2/3 T_{1/2} \end{aligned} \quad (5)$$

and similarly for $\rho\Sigma$, πY^* processes, etc. The corresponding isospin amplitudes for the πN induced analogues are

$$T(\pi^- p \rightarrow K^+ \Sigma^-) = T'_{3/2}$$

$$T(\pi^- p \rightarrow K^0 \Sigma^0) = \sqrt{2}/3 T'_{3/2} + \sqrt{2}/3 T'_{1/2} \quad (6)$$

$$T(\pi^+ p \rightarrow K^+ \Sigma^+) = 1/3 T'_{3/2} - 2/3 T'_{1/2}$$

Table 1 summarises the available data (at 4 GeV/c) for these processes.

One may use the three cross sections $\sigma(CD)(\equiv |T(AB \rightarrow CD)|^2)$ in each family to solve for $|T_{3/2}|$, $|T_{1/2}|$ and $\cos\varphi$, where φ is the relative phase. Where one piece of data is missing, one can instead obtain bounds, e.g.

$$\begin{aligned} \frac{3}{2} \sqrt{\frac{\sigma(\pi^- \Sigma^+)}{\sigma(\pi^+ \Sigma^-)}} - \frac{1}{2} &\leq |T_{1/2}/T_{3/2}| \leq \frac{3}{2} \sqrt{\frac{\sigma(\pi^- \Sigma^+)}{\sigma(\pi^+ \Sigma^-)}} + \frac{1}{2} \\ \frac{3}{\sqrt{2}} \sqrt{\frac{\sigma(K^0 \Sigma^0)}{\sigma(K^+ \Sigma^-)}} - 1 &\leq |T'_{1/2}/T'_{3/2}| \leq \frac{3}{\sqrt{2}} \sqrt{\frac{\sigma(K^0 \Sigma^0)}{\sigma(K^+ \Sigma^-)}} + 1 \end{aligned} \quad (7)$$

Results are summarized in table 2. There is little information on the relative phase between exotic and non-exotic amplitudes. However, their relative magnitude is quite well determined. One notices that:

- (a) The exotic suppression is most marked for the $0^- \frac{1}{2}^+$ production processes.
- (b) The degree of suppression is about the same for πN and $\bar{K} N$ processes (at least for 0^- production).
- (c) Although Σ/Y^* is small for 0^- production, the same appears not to be true for 1^- production, i.e. the suppression mechanism does not simply factorise (as it would for a single exotic exchange such as baryonium).

We shall make use of these observations in our discussions of Regge-Regge cuts (sect. 3) and baryonium (sect. 4).

The isospin exchange amplitudes for Ξ (and Ξ^*) production are

$$\begin{aligned} T(K^- p \rightarrow K^0 \Xi^0) &= 1/2 (T_1 + T_0) \\ T(K^- p \rightarrow K^+ \Xi^-) &= T_1 \end{aligned} \quad (8)$$

Both are exotic ($s = -2$ meson quantum numbers). It has to be noticed that this is the only exchange allowed in Ξ production in $\bar{K}N$ or πN scattering.

4. REGGE-REGGE CUTS

Models for Regge-Regge cuts have a much weaker theoretical basis than Regge poles. There are many serious theoretical problems and practical ambiguities involved [10]. For this reason, one is not justified in attempting other than simple order-of-magnitude calculations. The original cross section convolution prescription of Michael [11] is just this. The exotic process is thought of as a two-step process involving a single (lowest possible) intermediate state. Thus $K^- p \rightarrow \pi^+ \Sigma^-$ is the convolution of $K^- p \rightarrow \bar{K}^0 n$ and $\bar{K}^0 n \rightarrow \pi^+ \Sigma^-$ ($= K^- p \rightarrow \pi^- \Sigma^+$, by isospin). Each differential cross section σ_i is parametrised as

$$\sigma_i = A_i e^{b_i t} \mu b \text{ GeV}^{-2} \quad (9)$$

and the corresponding impact parameter space amplitudes are multiplied (ignoring phases) giving the two step differential and integrated cross sections as

$$\begin{aligned} \sigma_{12} &= A_{12} e^{b_{12} t} \\ \sigma_{12}^{\text{int}} &= A_{12}/b_{12} \end{aligned} \quad (10)$$

$$\begin{aligned} A_{12} &= A_1 A_2 [389.3 \pi (b_1 + b_2)^2]^{-1} \\ b_{12} &= b_1 b_2 / (b_1 + b_2) \end{aligned} \quad (11)$$

In the cases considered by Michael, spin could be neglected. However, in our case, we shall want to consider the convolution of helicity-flip dominated processes (F) with non-flip dominated process (N) to give an F-type process. Also, we shall want $F \otimes F$ giving both N and D (double flip). We therefore generalise Michael's prescription by using the

appropriate impact parameter transform [we take $\int \dots J(b\sqrt{-t}) \dots$ where $n = 0(N), 1(F), 2(D)$]. For F processes (eg. $K^- p \rightarrow \bar{K}^0 n$) eq. (9) becomes

$$\sigma_i = (-t) A_i e^{b_i t} \quad (9')$$

and for $F(\bar{x})N \rightarrow F$ we obtain^(*)

$$A_{12}(NF \rightarrow F) = A_1 A_2 b_2^2 [389.3 \pi (b_1 + b_2)^4]^{-1} \quad (11')$$

$$b_{12} = b_1 b_2 / (b_1 + b_2)$$

and $\sigma_{12}(FN \rightarrow F)$ is given in terms of these by (9'). For $F(\bar{x})F \rightarrow D$ we find^(*)

$$A_{12}(FF \rightarrow D) = A_1 A_2 b_1^2 b_2^2 [389.3 \pi (b_1 + b_2)^6]^{-1} \quad (11'')$$

and

$$\sigma_{12}(FF \rightarrow D) = (-t)^2 A_{12} e^{b_{12} t} \quad (12)$$

where b_{12} is (as always) given by (11). The possibility $F(\bar{x})F \rightarrow N$ is more complicated. We find

$$\sigma_{12}(FF \rightarrow N) = \frac{4 A_1 A_2}{\pi (b_1 + b_2)^4} (1 + b_{12} t / 2)^2 e^{b_{12} t} \quad (13)$$

Both possibilities $F(\bar{x})F \rightarrow N$ and $F(\bar{x})F \rightarrow D$ lead to the same integrated cross section however;

$$\begin{aligned} \sigma_{12}^{int}(NN \rightarrow N) &= A_{12}(NN \rightarrow N) / b_{12} \\ \sigma_{12}^{int}(FN \rightarrow F) &= A_{12}(FN \rightarrow F) / b_{12}^2 \\ \sigma_{12}^{int}(FF \rightarrow N, D) &= 2 A_{12}(FF \rightarrow D) / b_{12}^3. \end{aligned} \quad (14)$$

In table 3 are listed the various cross section parameters (eqs 9, 9') which we use as input. We convolute each "allowed" hypercharge exchange process with either $K^- p \rightarrow \bar{K}^0 n$ (for $K^- p$ processes) or $\pi^- p \rightarrow \pi^0 n$ (for $\pi^- p$) and obtain the results for the cross sections and slope parameters

(*) These results can be obtained directly by differentiation of eq. (10) with respect to the b_i (cf. eqs 9 and 9').

shown in the table. Of course, some processes are not completely F or N dominated: e.g. $K^- p \rightarrow \rho^0 \Sigma^0$ could be parametrised as an $F \otimes N \rightarrow F$ process in which case σ_{12}^{int} becomes $0.33 \mu\text{b}$ rather than $0.51 \mu\text{b}$.

Except for the $0^{-\frac{1}{2}+}$ processes, the results are considerably below the data at 4 GeV/c. In fact, the "Regge-Regge cut" (or, more correctly, cross section convolution) model predicts cross sections of order $1/2 \mu\text{b}$ for all the $K^- p$ induced processes and something around 10 times smaller for the analogous $\pi^- p$ processes. The data show that $0^{-\frac{1}{2}+}$ processes are especially suppressed (sect. 3) whereas the simple Regge-Regge cut model predicts similar results for all spin-parities. This is a significant point against the use of such models at 4 GeV/c. In fig. 5 we show a compilation of $0^{-\frac{1}{2}+}$, $0^{-\frac{3}{2}+}$ exotic exchange data above 2 GeV/c together with these naive Regge-Regge cut predictions. We assume that $\sigma^{\text{int}}(\text{CEX}) \sim p_{\text{lab}}^{-n_1}$, $\sigma^{\text{int}}(\text{HYCEX}) \sim p_{\text{lab}}^{-n_2}$ so that (apart from logarithmic factors)

$$\sigma_{12}^{\text{int}} \sim p_{\text{lab}}^{-(n_1 + n_2)} \quad (15)$$

where $n_1 = 1.5$, $n_2 = 2$. The most optimistic interpretation of these results, from a Regge-Regge cut point of view is that the t-channel picture is already valid by 4 GeV/c for $0^{-\frac{1}{2}+}$ processes, but that for resonant final states with higher thresholds (e.g. $0^{-\frac{3}{2}+}$), the transition from the s-channel domain is not yet complete.

The suppression of the $\pi^- p$ induced exotic processes relative to their $K^- p$ analogues is due partly to the similar (but less marked) behaviour of the non-exotic counterparts and partly to the steepness of the $\pi^- p$ CEX distribution relative to that of $K^- p$ CEX. Of course, one could deviate from our simplest possible model and allow πN intermediate states on the $\bar{K} N$ processes and vice versa (or indeed other SU(3) or SU(6) related states). We have arbitrarily restricted ourselves to the most probable first step process (i.e. CEX) which can lead to the desired final state. An alternative procedure would be to forgo any attempt to predict differences between πN and $\bar{K} N$ processes and just compare some kind of mean (e.g. root mean square) of the πN and $\bar{K} N$ values quoted in table 3.

For the Ξ production processes of eq. (8), one must consider HYCEX for both first and second steps, eg. $K^- p \rightarrow \pi^0 \Lambda^0 \rightarrow K^0 \Xi^0$. Of course, the intermediate state could just as well be $\pi^0 \Sigma^0$ or $\pi^- \Sigma^+$ and so one has to add these using SU(2) and SU(3). Since the second step process is unmeasurable, one again has to use SU(3) to relate to the first step. The results are exceedingly sensitive to the assumed SU(3) F/D parameter i.e., $\sigma^{\text{int}}(K^0 \Xi^0) = .016 (.13)$, $\sigma^{\text{int}}(K^+ \Xi^-) = .0011(1.8) \mu\text{b}$ for F/D = -3 (0.4). The first F/D value is relevant for K^* (non-flip) dominance of HYCEX and the second for K^* (flip) or K exchange. Since the first is more likely, we conclude that the predictions are again very small relative to the data ($\sigma(K^+ \Xi^-) = 1.3 \pm .2 \mu\text{b}$).

The angular distribution for the process $\pi^- p \rightarrow K^+ \Sigma^-$ has been studied by Akerlof et al., [12]. They find that at 4 and 5 GeV/c, $d\sigma/dt$ shows a forward turn-over characteristic of a helicity-flip dominated process. In fact, this is what is expected in the cross section convolution model considered here (or indeed any simple Regge-Regge cut model). According to our scheme $K^+ \Sigma^-$ and $\pi^+ \Sigma^-$ production are F Type ($= F \otimes N$), $K^+ Y^{*-}$ and $\pi^+ Y^{*-}$ are N ($= F \otimes F$) and $K\bar{\Xi}$ are N ($= N \otimes N$).

5. BARYONIUM EXCHANGE

The motivation for considering baryonium exchange has weakened considerably since Nicolescu reviewed the subject [2]. Since there remains scarcely a single candidate for such states in the mass spectrum [3], there are no practical constraints on the expected trajectory and coupling parameters.

Nicolescu proposed the following properties as qualitative tests of the idea [2]:

- (a) Existence of forward (exotic) peaks.
- (b) Break in the s-dependence of cross sections when truly exotic exchanges predominate.

- (c) Weaker coupling of exotic exchange in MB (meson-baryon) scattering compared to BB.
- (d) Comparable Regge residues for meson and baryonium coupling to $B\bar{B}$.

Let us compare these with the corresponding properties of Regge-Regge cuts. Clearly, properties (a) and (b) are also characteristic of double Regge exchange and so they do not provide a unique test. Nicolescu suggests a baryonium trajectory of $\alpha_B \sim -0.5$ to -1 , i.e. $\sigma^{\text{int}} \sim s^{-3}$ or s^{-4} which is not very different from the Regge-Regge cut expectation (eq. 15) of $s^{-3.5}$. In both models one expects this behaviour to set in only when s-channel effects have died out.

Property (c), at first sight, looks to be a distinctive test since Regge-Regge cuts are rather similar in MB and BB scattering. A promising example proposed in ref. [2] is the ratio $\sigma(\pi^- p \rightarrow \pi^+ \Delta^-) / \sigma(pn \rightarrow \Delta^- \Delta^{++})$ which, indeed, turns out to be very small ($\sim 1/25$ to $1/50$) [2]. In Regge-Regge cut language, the numerator is the convolution of two ρ exchange processes ($\pi^- p \rightarrow \pi^0 n \circledast \pi^0 n \rightarrow \pi^+ \Delta^-$) whereas the denominator involves π exchange ($pn \rightarrow np \circledast np \rightarrow \Delta^- \Delta^{++}$). Using the methods of sect. 4 we estimate the ratio to be $\sim 1/100$ at 4 GeV/c^(*). Similarly, for $I = 3/2$ exchange (eg. $\pi^- p \rightarrow K^+ Y^{*-}$ relative to $\bar{p}p \rightarrow Y^{*-} Y^{*-}$) we expect a suppression which is less marked ($\rho \circledast K^*$ exchange relative to $\pi \circledast K$ exchange). The data show a ratio $\sim 1/6$ at 4 GeV/c. Again, the baryonium exchange prediction turns out to be qualitatively similar to a Regge-Regge cut model.

Finally, what are the effective coupling to baryons in each model? Nicolescu expects the ratio of effective residues of baryonium (β) and normal meson (R)

$$\beta_B^2 / \beta_R^2 = (\sigma_B / \sigma_R) (s/s_0)^{2(\alpha_R(0) - \alpha_B(0))} \quad (16)$$

to be of order one (assuming $s_0 = 1 \text{ GeV}^2$) [2]. We can express the Regge-Regge cut predictions in a similar fashion. Suppose (see eq. (9))

(*) $\pi N \rightarrow \pi \Delta$ is treated as $F \circledast F \rightarrow N, D$ (see sec. 4) whereas $NN \rightarrow \Delta \Delta$ is assumed to be $N \circledast N \rightarrow N$ ($np \rightarrow pn$ has a forward spike associated with π exchange).

$$\begin{aligned} A_R &= \beta_R^2 (s/s_0)^{2\alpha_R(0)-2} \\ b_R &= b_0 + 2\alpha' \log(s/s_0) \end{aligned} \quad (17)$$

so that by eqs 16 and 11

$$\beta_{R(x)}^2 / \beta_R^2 = (\beta_R / b_R)^2 / (2\pi \cdot 389.3) \quad (18)$$

For π exchange, $\beta_R \sim 800$, $b_R \sim 25$ (e.g. $np \rightarrow pn$) so that

$$\beta_{R(x)}^2 / \beta_R^2 \sim 0.4 \quad (19)$$

which is clearly of order 1.

The suppression of $0^{-\frac{1}{2}+}$ production relative to $0^{-\frac{3}{2}+}$ or $1^{-\frac{3}{2}+}$, etc. is a problem for both Regge-Regge cut models (sec. 4) and for baryonium exchange. The effect cannot be understood as a suppression of the baryonium coupling to $\bar{p}\Sigma^-$ due to symmetry (SU(6)) as suggested in ref. [2]. We have already observed (point (c), sect. 3) that the suppression does not factorise. Neither can it be explained [2] as a mass-dependent effect predicted by triple Regge arguments since the suppression factor, for example, $(m_Y^{2*}/m_\Sigma^2)^{2\alpha_B(0)}$ is only around .65 compared with .1 to .2 in the data.

We conclude that the testable predictions of baryonium exchange models are not drastically different from those of naive Regge-Regge cut models and so cannot, at present, be used to help establish a case for the existence of baryonium states in nature.

6. DOUBLE SCATTERING QUARK MODEL

6.1 Σ, Y^* production

The additive quark model provides a very simple and surprisingly accurate description of many features of non-exotic exchange processes [13]. Each scattering particle interacts via only one of its constituent quarks at a time. Bialas and Zalewski [4] have generalised this model to describe exotic exchange processes by allowing two constituent quarks to

participate. This provides relations between the spin amplitudes (transversity amplitudes most simply) of, for example, $0^{-\frac{1}{2}} \rightarrow 0^{-\frac{1}{2}}$ and $0^{-\frac{3}{2}}$ exotic exchange processes. As a by-product, it provides a mechanism for the quark model "forbidden" double transversity - flip amplitude observed in the corresponding "allowed" process e.g. $K^- p \rightarrow \pi^- Y^{*+}$ [14] (see the isospin relations of eq. 5).

In the notation of ref. [4], we find^(*) for $\pi^- p \rightarrow K^+ \Sigma^-$ and $K^+ Y^{*-}$,

$$\begin{aligned} T(K\Sigma)_{\pm \frac{1}{2} \pm \frac{1}{2}} &= 1/3(a_{\pm} \bar{b}_{\pm} - 2a_{+} \bar{b}_{-}) \\ T(KY^{*})_{\pm \frac{1}{2} \pm \frac{1}{2}} &= \mp \sqrt{2/3}(a_{\pm} \bar{b}_{+} + a_{+} \bar{b}_{\pm}) \\ T(KY^{*})_{\frac{3}{2} \pm \frac{1}{2}} &= \pm \sqrt{8/3} a_{\pm} \bar{b}_{\pm} \end{aligned} \quad (20)$$

where $T_{m'm}$ are transversity amplitudes and $\bar{a}_{\pm}$ ($\bar{b}_{\pm}$) is the amplitude for emission of a π^{+} from a transversity $\pm 1/2$ u quark (K^{+} from a d quark). Each "product" $a_m \cdot \bar{b}_m$ contains an implicit sum over intermediate states (see ref. [4] for details). The equations for the processes $K^- p \rightarrow \pi^{+} \Sigma^-$ and $\pi^{+} Y^{*-}$ are identical to eq. (20) with the substitution $a_{\pm} \rightarrow b_{\pm}$ and $\bar{b}_{\pm} \rightarrow \bar{a}_{\pm}$ (a is the π^{-} absorption amplitude corresponding to the π^{+} emission amplitude $\bar{a}$ defined above).

If, as in ref. [4], one takes the $\pi^{+} \Sigma^{-}$ cross section to be identically zero, one deduces that the amplitudes $a_{+} \bar{b}_{\pm}$ must vanish and so obtain the prediction that the $\pi^{+} Y^{*-}$ cross section is pure transversity $3/2$ ($\sigma_{1/2}(\pi^{+} Y^{*-}) = 0$). Until recently this seemed to be in accord with the data [14]. However, as recently pointed out in ref. [1], finite values for both $\sigma(\pi^{+} \Sigma^{-})$ and $\sigma(K^{+} \Sigma^{-})$ have been established (table 1) and so the situation must be reexamined. If polarisation data for these exotic processes were available, one would test the double scattering quark model (DSQM) by actually solving for the amplitude combinations in eq. 20. In its absence, one can still obtain the simple bound that

(*) In ref. [4], the factor $\sqrt{2/3}$ is omitted in the amplitudes $T(KY^{*})_{\pm \frac{1}{2} \pm \frac{1}{2}}$.

$$\sigma_{1/2}(\pi^+ Y^{*-}) \leq 8\sigma(\pi^+ \Sigma^-) \quad (21)$$

$$\sigma_{1/2}(K^+ Y^{*-}) \leq 8\sigma(K^+ \Sigma^-)$$

where $\sigma_{1/2}$ means the cross section for producing a Y^* in transversity $\pm \frac{1}{2}$. Using the data in table 1 and the fact that $\sigma_{3/2} = \sigma - \sigma_{1/2}$ we find

$$\sigma_{3/2}/\sigma(\pi^+ Y^{*-}) \geq 1 - 8\sigma(\pi^+ \Sigma^-)/\sigma(\pi^+ Y^{*-}) = -1. \pm .7 \quad (22)$$

$$\sigma_{3/2}/\sigma(K^+ Y^{*-}) \geq 1 - 8\sigma(K^+ \Sigma^-)/\sigma(K^+ Y^{*-}) = -.2 \pm .7.$$

There is no inconsistency with these bounds. In fact, amplitude analysis of these Y^* production processes suggests (*) that for $|t'| < .5$ [15]

$$\sigma_{3/2}/\sigma(\pi^+ Y^{*-}) = .16 \pm .11 \quad (23)$$

$$\sigma_{3/2}/\sigma(K^+ Y^{*-}) = .70 \pm .24.$$

Only for the process $\pi^- p \rightarrow K^+ Y^{*-}$, are the transversity $\pm 3/2$ amplitudes dominant (**), as predicted in the original application of the DSQM by Bialas and Zalewski [4].

One can extend the DSQM to describe processes of the type $0^{-\frac{1}{2}+} \rightarrow 1^{-\frac{1}{2}+}$ and $1^{-\frac{3}{2}-}$, by defining amplitudes $\bar{a}_{\pm}(m)$, $\bar{b}_{\pm}(m)$ corresponding to the emission of a vector particle of transversity m . However, the spin structure of the quark transition is different depending on m (because of parity) so that one obtains equations analogous to (20) which are structurally different for each vector particle spin state. Since the spin polarization information is rather limited for exotic processes, such relations are of little practical use.

(*) We have used the relation $\sigma_{3/2}/\sigma = \frac{1}{4} \rho_{1/2 \ 1/2}^H - \sqrt{3} \rho_{3/2-1/2}^H$ where the latter are s-channel helicity density matrix elements.

(**) A similar result for the $K^- p$ process [14] did not fully take into account the effect of reflections from the $\rho\Lambda$ final state [15].

6.2 Ξ, Ξ^* production

If we let $\bar{b}'_{\pm}$ be the effective amplitude for the emission of a K^0 from a transversity $\pm 1/2$ d quark, we can obtain DSQM predictions for Ξ and Ξ^* production

$$\begin{aligned} T(K^+ \Xi^-)_{\pm \frac{1}{2} \pm \frac{1}{2}} &= \frac{1}{\sqrt{2}} T(K^+ \Xi^{*-})_{\pm \frac{1}{2} \pm \frac{1}{2}} = \frac{1}{3} (b_+ \bar{b}_- + b_- \bar{b}_+) \\ T(K^+ \Xi^{*-})_{\pm \frac{3}{2} \pm \frac{1}{2}} &= \pm \sqrt{\frac{8}{3}} b_{\pm} \bar{b}_{\pm} \end{aligned} \quad (24)$$

and

$$\begin{aligned} T(K^0 \Xi^0)_{\pm \frac{1}{2} \pm \frac{1}{2}} &= \frac{1}{\sqrt{2}} T(K^0 \Xi^{*0})_{\pm \frac{1}{2} \pm \frac{1}{2}} = \frac{1}{3} (b_+ \bar{b}'_{\pm} - 2b_{\pm} \bar{b}'_{\pm}) \\ T(K^0 \Xi^{*0})_{\pm \frac{3}{2} \pm \frac{1}{2}} &= \mp \sqrt{\frac{2}{3}} b_{\pm} \bar{b}'_{\pm} . \end{aligned} \quad (25)$$

Because of the very different symmetry properties of the Ξ and Σ in SU(6), we obtain now a different set of relations than those resulting from eq. (20). Instead of the bounds (eq. (21)) we have the equality

$$\sigma_{1/2}(K\Xi^*) = 2\sigma(K\Xi) . \quad (26)$$

Proceeding as for eq. (22) we deduce (using table 1)

$$\begin{aligned} \sigma_{3/2}(K^+ \Xi^{*-}) &= (.7 \pm .4) - (2.6 \pm .4) = -1.9 \pm .6 \text{ } \mu\text{b} \\ \sigma_{3/2}(K^0 \Xi^{*0}) &= (1.0 \pm .2) - (< 16) \leq 1.0 \text{ } \mu\text{b} . \end{aligned} \quad (27)$$

Thus although we have a contradiction in the Ξ^-, Ξ^{*-} production case, we can say nothing about Ξ^{*0} production since we have not been able to measure directly the corresponding cross section. The discrepancy stems ultimately from the fact that octet production is not heavily suppressed in Ξ production (unlike Σ) although the DSQM suggests Ξ and Σ production are somewhat similar.

A simple prediction of the DSQM which follows from eq. (24) is that the polarisation in $K^- p \rightarrow K^+ \Xi^-$ is zero (since $T(K^+ \Xi^-)_{+1/2+1/2} = T(K^+ \Xi^-)_{-1/2-1/2}$). This, however, will be difficult to test.

One can go further. If the intermediate quark produced by, for example, the amplitude $\bar{b}_+$ could be treated as non interacting we could use isospin invariance and obtain

$$\bar{b}'_{\pm} = \bar{b}_{\pm} \quad (28)$$

and so relate Ξ^0 to Ξ^- production (eqs (24,25)). Thus

$$\sigma_{3/2}(K^+ \Xi^{*-}) = 4 \sigma_{3/2}(K^0 \Xi^{*0}) \quad (29)$$

and (cf. eq. (21))

$$\sigma(K^+ \Xi^-) < 4\sigma(K^0 \Xi^0) . \quad (30)$$

With the available data none of these relations can be significantly tested.

Note, however, that these last relations (29,30) follow from an extra assumption beyond the DSQM proposed by Bialas and Zalewski [4].

6.3 Non-exotic processes

One can use the DSQM to estimate the double transversity flip amplitudes $T(Y^*)_{\mp 3/2 \pm 1/2}$ in non-exotic exchange processes. To relate a family of processes, e.g. $\pi^- p \rightarrow K^0 Y^{*0}$, $\pi^+ p \rightarrow K^+ Y^{*+}$ and $\pi^- p \rightarrow K^+ Y^{*-}$, one must use the "isospin" relation (28) and a similar one relating π absorption ($a_{\pm}$) to π^+ absorption ($a'_{\pm}$). In this way we find:

$$\begin{aligned} \sigma_{3/2}(K^+ Y^{*+}) &= 2\sigma_{3/2}(K^0 Y^{*0}) = 1/4 \sigma_{3/2}(K^+ Y^{*-}) \\ \sigma_{3/2}(\pi^- Y^{*+}) &= \frac{1}{4} \sigma_{3/2}(\pi^+ Y^{*-}) \end{aligned} \quad (31)$$

Note that this last relation differs from the naive assumption of equal cross sections used in ref. [14]. Taking the exotic exchange cross sections from table 1 as upper limits for $\sigma_{3/2}$, we then predict

$$\begin{aligned} \sigma_{3/2}(\pi^- Y^{*+}) &< .6 \pm .1 \mu b & (2.2 \pm .5) \mu b \\ \sigma_{3/2}(K^0 Y^{*0}) &< .24 \pm .05 \mu b & (3 \pm 1) \mu b. \end{aligned} \quad (32)$$

The bracketed numbers are estimates from direct amplitude analysis [15]. We conclude that this extension (isospin applied to the effective amplitudes) of the DSQM does not explain the large additive quark model violations observed in these Y^* production processes.

6.4 SU(6) breaking

It is well known that the additive quark model is not at its best when relating octet to decuplet baryons presumably because of SU(6) breaking in the wave functions [16]. Different ways of allowing for the SU(6) breaking have been shown [17,18] to give good agreement with data on Λ , Σ and Y^* production by hypercharge exchange. One might reasonably ask what is the effect of using these modified baryon wave functions in the DSQM?

The modifications to the DSQM relations (eq. (20), for example) turn out to be very simple. Assuming SU(3) remains a good symmetry (which it appears to be, at least for couplings) we find that in eq. (20), the expressions for $T_{m'm}^{(\Sigma)}$ get multiplied by $\sin 2\Gamma$ and those for $T_{m'm}^{(Y^*)}$ get multiplied by $\cos(\Gamma - \pi/4)$. Here, Γ is an angle characterising the amount of SU(6) breaking [16]. For exact SU(6) it is $\pi/4$ (so that we recover eq. (20)) whereas Zralek et al., [17] find that $\Gamma \sim 53^\circ$ gives a good fit to (non-exotic) hypercharge exchange processes. Since this means $\sin 2\Gamma \sim .96$, $\cos(\Gamma - \pi/4) \sim .99$, the consequences are unobservably small.

Kluyver et al., [18] have considered breaking SU(6) in the proton wave function alone (not for Σ or Y^*). This, of course, corresponds to a violation of SU(3). In this case one finds that eqs (20) are scaled overall by a unobservable factor $\cos(\Gamma_1 - \pi/4)$ where, incidentally, $\Gamma_1 = \pi/3$ is recommended [18].

The effect of SU(6) breaking on the Ξ , Ξ^* production relations is the same, i.e. octet production amplitudes are multiplied by $\sin 2\Gamma$ and decuplet ones by $\cos(\Gamma - \pi/4)$. Since these effects are negligible, we conclude that the tests of the DSQM outlined above are significant in that they test the principles of the model rather than uncertain details of the constituent wave functions.

7. CONCLUSIONS

We have used exotic exchange data in the neighbourhood of 4 GeV/c (including hitherto unpublished data on $\pi^- p \rightarrow K^+ \Sigma^-$, $K^{*+} \Sigma^-$, $K^{*+} Y^-$ and $K^- p \rightarrow \rho^+ \Sigma^-$, $K^0 \Xi^0$) to test different theoretical models. The rich variety of information on families of $\pi^- p$ and $K^- p$ induced processes has enabled us to make quite stringent tests. Models considered were:

- (a) The b-space convolution of two non-exotic processes (loosely termed Regge-Regge cut model).
- (b) Baryonium exotic Regge pole exchange.
- (c) The Bialas and Zalewski double scattering quark model (DSQM).

It was shown that the predictions of the first two models are so similar in practice that one cannot use existing data to discriminate between them. Because of this, one cannot, as yet, use exotic exchange data to provide evidence for or against baryonium exchange (and by implication the existence of baryonium states themselves).

Only for $K^- p \rightarrow \pi^+ \Sigma^-$ did a Regge-Regge cut model provide a realistic description. The model fails to provide a satisfactory explanation of the suppression of exotic exchange in $0^- \frac{1}{2}$ processes as compared to $0^- \frac{3}{2}$ or $1^- \frac{3}{2}$, for example. This certainly disfavours it (baryonium exchange is no better in this regard). Perhaps asymptotic behaviour sets in more slowly in the higher threshold channels.

We have made detailed tests of the Bialas and Zalewski DSQM for Σ and Y^* production and also Ξ and Ξ^* production by exotic exchange. The model is compatible with data for the first set of processes, but not for the second. The effects of SU(6)-breaking, established for non-exotic exchange, were investigated and found to be negligible. The model's failure for Ξ and Ξ^* production thus appears to be significant.

In summary, it seems that there is considerable evidence for small exotic exchange cross sections at intermediate energy but that their absolute and relative magnitudes are not described in detail by the available models. However, the fact that they are indeed so small relative to their non-exotic exchange counterparts remains an impressive demonstration of t-channel dynamics at work.

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TABLE CAPTIONS

- TABLE 1 The integrated cross sections for various final states in K^-p and $\pi^{\pm}p$ scattering near 4 GeV/c (actually 4.2 GeV/c for $\bar{K}N$ and 3.95 GeV/c for πN).
- TABLE 2 The exchanged isospin amplitude decomposition for various processes in the $|t'| < 1 \text{ GeV}^2$ region.
- TABLE 3 The input cross section parameters and corresponding Regge-Regge cut predictions at 4 GeV/c obtained as described in the text. For an $F(x)F$ calculation there are two possible differential cross sections behaviour (N,D) although the integrated cross section is unique. Crude estimates for the A and b parameters were obtained from data referenced in table 1. The $K^-p \rightarrow \bar{K}^0n$ and $\pi^-p \rightarrow \pi^0n$ estimates were made from the data of refs [27,28].

TABLE 1

$K^- p \rightarrow$	Ref.	$\sigma(t' < 1)$ μb	$\pi^\pm p \rightarrow$	Ref.	$\sigma(t' < 1)$ μb	Type
$\pi^+ \Sigma^-$	[1]	$.6 \pm .1$	$K^+ \Sigma^-$		$.29 \pm .10$	$0^- \frac{1}{2}^+$
$\pi^- \Sigma^+$	[1]	119 ± 6	$K^0 \Sigma^0$	[5]	32 ± 2	
$\pi^0 \Sigma^0$	-		$K^+ \Sigma^+$	[19]	58 ± 4	
$\pi^+ Y^{*-}$	[15]	$2.4 \pm .4$	$K^+ Y^{*-}$	[15]	$1.9 \pm .4$	$0^- \frac{3}{2}^+$
$\pi^- Y^{*+}$	[15]	64 ± 3	$K^0 Y^{*0}$	[15]	20 ± 2	
$\pi^0 Y^{*0}$	-		$K^+ Y^{*+}$	[21]	21 ± 4	
$\rho^+ \Sigma^-$		2.5 ± 1.0	$K^{*+} \Sigma^-$		2.5 ± 0.8	$1^- \frac{1}{2}^+$
$\rho^- \Sigma^+$	[20]	45 ± 10	$K^{*0} \Sigma^0$	[6]	25 ± 2	
$\rho^0 \Sigma^0$	[31]	15 ± 2	$K^{*+} \Sigma^+$	[21-23]	45 ± 10	
$\rho^+ Y^{*-}$	[6]	< 1	$K^{*+} Y^{*-}$		$2.6 \pm .8^{(a)}$	$1^- \frac{3}{2}^+$
$\rho^- Y^{*+}$	[6]	67 ± 3	$K^{*0} Y^{*0}$	[6]	23.4 ± 3.0	
$\rho^0 Y^{*0}$	[26]	9 ± 6	$K^{*+} Y^{*+}$	[21,24,25]	32 ± 13	
$K^0 \Xi^0$		< 8				$0^- \frac{1}{2}^+$
$K^+ \Xi^-$	[7]	$1.3 \pm .2$				
$K^0 \Xi^{*0}$	[7]	$1.0 \pm .2$				$0^- \frac{3}{2}^+$
$K^+ \Xi^{*-}$	[7]	$.7 \pm .4$				
$K^{*0} \Xi^0$	-					$1^- \frac{1}{2}^+$
$K^{*+} \Xi^-$	[7]	$1.0 \pm .2$				
$K^{*0} \Xi^{*0}$	[7]	$2.0 \pm .4$				$1^- \frac{3}{2}^+$
$K^{*-} \Xi^{*-}$	[7]	$< .7$				

(a) Full forward cross section.

TABLE 2

Process	$ T_{3/2} ^2$ μb	$ T_{3/2}/T_{1/2} $	$\cos\phi$
$K^- p \rightarrow \pi \Sigma$	$.6 \pm .1$	$.048 \pm .005$	-
$\pi p \rightarrow K \Sigma$	$.29 \pm .10$	$.047 \pm .008$	$.7 \pm .6$
$K^- p \rightarrow \pi Y^*$	$2.4 \pm .4$	$.13 \pm .014$	-
$\pi p \rightarrow K Y^*$	$1.9 \pm .4$	$.18 \pm .03$	$1.4 \pm .6$
$K^- p \rightarrow \rho \Sigma$	2.5 ± 1.0	$.16 \pm .06$	$.5 \pm .5$
$\pi p \rightarrow K^* \Sigma$	$2.5 \pm .8$	$.16 \pm .03$	$.2 \pm .5$
$K^- p \rightarrow \rho Y^*$	< 1	$< .12$	
$\pi p \rightarrow K^* Y^*$	$2.6 \pm .8$	$.18 \pm .05$	$.8 \pm .7$

TABLE 3

Process	Type	A $\mu\text{b GeV}^{-2}$	b GeV^{-2}	Exotic process	Type	A ₁₂	b ₁₂	σ_{12}^{int} (μb)	Data σ_{forward} (μb)
$\text{K}^- \text{p} \rightarrow \bar{\text{K}}^0 \text{n}$ $\pi^- \text{p} \rightarrow \pi^0 \text{n}$	F F	10,100 28,000	6.8 14.4						
$\text{K}^- \text{p} \rightarrow \pi^- \Sigma^+$ $\pi^- \text{p} \rightarrow \text{K}^0 \Sigma^0$	N N	750 300	6.0 9.4	$\text{K}^- \text{p} \rightarrow \pi^+ \Sigma^-$ $\pi^- \text{p} \rightarrow \text{K}^+ \Sigma^-$	FN $\rightarrow$ F	8.3 1.9	3.2 5.7	.82 .06	.6 $\pm$.1 .29 $\pm$.10
$\text{K}^- \text{p} \rightarrow \pi^- \text{Y}^{*+}$ $\pi^- \text{p} \rightarrow \text{K}^0 \text{Y}^{*0}$	F F	2,000 515	5.4 5.2	$\text{K}^- \text{p} \rightarrow \pi^+ \text{Y}^{*-}$ $\pi^- \text{p} \rightarrow \text{K}^+ \text{Y}^{*-}$	FF $\rightarrow$ N(D)	.99 (6.8) .32 (1.2)	3.0 3.8	.50 .04	2.4 $\pm$.4 1.9 $\pm$.4
$\text{K}^- \text{p} \rightarrow \rho^0 \Sigma^0(a)$ $\pi^- \text{p} \rightarrow \text{K}^{*0} \Sigma^0$	F F	306 628	4.3 5.1	$\text{K}^- \text{p} \rightarrow \rho^+ \Sigma^-$ $\pi^- \text{p} \rightarrow \text{K}^{*+} \Sigma^-$	FF $\rightarrow$ N(D)	2.7 (4.6) .40 (1.4)	2.6 3.8	.51 .05	2.5 $\pm$ 1.0 2.5 $\pm$.8
$\text{K}^- \text{p} \rightarrow \rho^- \text{Y}^{*+}$ $\pi^- \text{p} \rightarrow \text{K}^{*0} \text{Y}^{*0}$	N N	195 55	3.6 2.1	$\text{K}^- \text{p} \rightarrow \rho^+ \text{Y}^{*-}$ $\pi^- \text{p} \rightarrow \text{K}^{*+} \text{Y}^{*-}$	FN $\rightarrow$ F	1.8 .08	2.4 1.8	.32 .02	< 1 2.6 $\pm$.8

(a) Four times this cross section (by isospin relations) is used in the calculation.

FIGURE CAPTIONS

- Fig. 1 Differential cross section for the reaction $\pi^- p \rightarrow K^+ \Sigma^-$ at 3.95 GeV/c.
- Fig. 2 $M^2(K_s^0 \pi^+)$ vs $(-t)$ scatter plot for the reaction $\pi^- p \rightarrow K^0 \pi^+ \Sigma^-$ at 3.95 GeV/c. The low mass Y^* 's present in the $\pi^+ \Sigma^-$ mass combination have been excluded by requiring $\cos \theta_H < .3$ where θ_H is the s-channel helicity polar decay angle of the $K^0 \pi^+$ system.
- Fig. 3 $M(K^+ \pi^0)$ vs $M(\Lambda_s^- \pi^-)$ scatter plot for the reaction $\pi^- p \rightarrow K^+ \pi^- \pi^0 \Lambda$ at 3.95 GeV/c after antiselection of the K^{*0} and Y^{*0} signals in the $K^+ \pi^-$ and $\Lambda_s^- \pi^0$ mass combinations respectively.
- Fig. 4 $M(\pi^+ \pi^0)$ spectrum for the reaction $K^- p \rightarrow \pi^+ \pi^0 \Sigma$ at 4.2 GeV/c. The cuts applied to the data are specified in the text. The curve is the result of the fit described in the text.
- Fig. 5 The forward integrated cross section for the processes (a) $K^- p \rightarrow \pi^+ \Sigma^-$, $\pi^- p \rightarrow K^+ \Sigma^-$ and (b) $K^- p \rightarrow \pi^+ Y^{*-}$, $\pi^- p \rightarrow K^+ Y^{*-}$. Where known, the cross section for $|t'| < 1 \text{ GeV}^2$ has been used. The Y^* data are from the compilation of ref. [2]. The Σ data are from Dahl et al., [29], London et al., [30] and from this experiment (table 1). For comparison, the squares show the $d\sigma/dt(0^\circ)$ data of Akerlof et al., [12] multiplied by the factor 2.9 GeV^2 (so that the $\pi^- p \rightarrow K^+ \Sigma^-$ value corresponds with our value of $\sigma(|t'| < 1)$ measured at 4 GeV/c). The straight lines are the model expectation for the r.m.s. value of $\pi^- p$ and $K^- p$ channels as described in the text.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5