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HYPERCHARGE EXCHANGE LINE - REVERSED REACTIONS
AND ASYMPTOTIC MODELS

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A B S T R A C T

The asymptotic behaviour of the line-reversed reactions $\bar{K}N \rightarrow \pi \Sigma$, $\pi \Lambda$ and $\pi N \rightarrow K \Sigma$, $K \Lambda$ is compared with model predictions. Polarization data favour an exchange degenerate Regge cut model and tests involving R and A parameters are discussed. An s channel approach to the observed inequality of line-reversed cross-sections at lower energies is presented.

Two-body scattering at high energies is conventionally analyzed from an angular momentum plane approach, with Regge pole dominance as the simplest such model. Existing data have, however, many intricate features and it has been found necessary to use more sophisticated models. Regge pole models may be extended by employing further secondary trajectories, effective Regge poles (which do not factorize), complex Regge poles (which have the phase-energy dependence relation relaxed), or Regge cuts. The Regge cut models of absorption type further subdivide into those with underlying (A) exchange degenerate poles, or (B) structureless poles. We shall be concerned primarily with the E.X.D. pole plus cut model (A) since it has considerable predictive power, and shall also discuss the Michigan model (B) which also becomes predictive when one adds the "systematics" of cut-pole cancellation ¹⁾ at $-t \sim 0.2$ and 0.6 GeV^2 in s channel non-flip and single-flip helicity amplitudes, respectively. Non-asymptotic contributions from Regge cuts and from s channel resonances will be discussed and we shall introduce duality considerations.

DATA

The reactions $\bar{K}N \rightarrow \pi \Sigma, \pi \Lambda$ and $\pi N \rightarrow K \Sigma, K \Lambda$ which we shall discuss primarily are a very rich testing ground for high-energy models. The crossing relation between them is crucial in testing whether a model for $K^* - K^{**}$ exchange is asymptotic or just fits data in a limited region of s . In addition to the cross-section data, there are sufficient polarization data to illuminate the spin decomposition of the amplitudes. The only other measurable quantity is R (or equivalently A since $P^2 + R^2 + A^2 = 1$) and it will provide a last chance ²⁾ of distinguishing high-energy theories if present data are insufficient. Before comparing the expectations of different models, we present a review of the present experimental data.

a) - Dips

$d\sigma/dt$ data ^{3),4)} show a forward peak (with no turnover at $t = t_{\min}$) of slope $4 - 10 \text{ GeV}^{-2}$ with a break to a flatter slope at $t \sim -0.4 \text{ GeV}^2$. This shoulder or break is most pronounced for $\pi^+ p \rightarrow K^+ \Sigma^+$ where it disappears rapidly with energy from 3 to 14 GeV/c.

b) - Shrinkage

We present a sample of $d\sigma/dt$ data in Fig. 1 for $\pi^+ p \rightarrow K^+ \Sigma^+$ and $K^- p \rightarrow \pi^- \Sigma^+$ at fixed t values as a function of energy. The slopes on such a plot yield α_{eff} for the relevant t value. One finds $\alpha_{\text{eff}} \sim 0.3 + 0.4 t$ for $K^- p \rightarrow \pi^- \Sigma^+$ and $\alpha_{\text{eff}} \sim 0.6 + 1.1 t$ for $\pi^+ p \rightarrow K^+ \Sigma^+$. The data for the reactions with Σ replaced by Λ extend to less high energies but α_{eff} values are compatible ^{*}). In summary $\bar{K}N \rightarrow \pi \Sigma, \pi \Lambda$ shows little shrinkage and $\alpha_0 \sim 0.3$ while $\pi p \rightarrow K \Sigma, K \Lambda$ shrinks strongly and has an intercept $\alpha_0 \sim 0.6$, much higher than the expected 0.35 for a $K^* - K^{**}$ trajectory.

c) - Crossing

In all models the line-reversed amplitudes and cross-sections are equal asymptotically. At 3-5 GeV/c, however, $d\sigma/dt$ for $\pi^+ p \rightarrow K^+ \Sigma^+$ relative to $d\sigma/dt$ for $K^- p \rightarrow \pi^- \Sigma^+$ is smaller for $t \neq 0$ by a factor of up to 2 and has a somewhat steeper t dependence. For the Λ data, the same situation applies, with the slope difference between $\pi N \rightarrow K \Lambda$ (steep) and $\bar{K}N \rightarrow \pi \Lambda$ (flatter) being more pronounced. It is of interest to note that for another pair of line-reversed reactions, KN and $\bar{K}N$ charge exchange, the $d\sigma/dt$ data ⁵⁾ are consistent with equality above 5 GeV/c. There is some indication of a similar approach to equality for the line-reversed

^{*}) However, Bertolucci et al. in $\pi^- p \rightarrow K^0 (\Sigma^0 + \Lambda^0)$ at 6 - 11.2 GeV/c find $\alpha_{\text{eff}} = 0.34 + 0.15 t$ which is in marked contrast to the $\pi^+ p \rightarrow K^+ \Sigma^+$ (4 - 14 GeV/c) values and the $\pi^- p \rightarrow K^0 \Lambda^0$ (3 - 8 GeV/c) values.

$K^* - K^{**}$ exchange data :

- i) the slope in $\pi^- p \rightarrow K^0 \Lambda^0$ at 8 and 10 GeV/c is consistent with that from $\bar{K}^0 p \rightarrow \Lambda \pi^+$ at 5-8 GeV/c ;
- ii) as shown in Fig. 1, the $\pi^+ p \rightarrow K^+ \Sigma^+$ data at 10 and 14 GeV/c are consistent in magnitude with the $K^- p \rightarrow \pi^- \Sigma^+$ data ^{*)} at 8 and 16 GeV/c. Also preliminary $\pi^+ p \rightarrow K^+ \Sigma^+$ data at 2.75-5.5 GeV/c for $|t| < 0.1$ lie close to the $K^- p \rightarrow \pi^- \Sigma^+$ data.

d) - Exotic exchange

The exotic exchange reactions $\pi^- p \rightarrow K^+ \Sigma^-$ and $K^- p \rightarrow \pi^+ \Sigma^-$ have forward cross-sections ³⁾ relative to the allowed processes of $\sim 1\%$ at 3 GeV/c and $< 0.1\%$ above 5 GeV/c. The comparison of the slopes of $\pi^- p \rightarrow K^0 \Sigma^0$ with $\pi^+ p \rightarrow K^+ \Sigma^+$ and of $K^- n \rightarrow \pi^- \Sigma^0$ with $K^- p \rightarrow \pi^- \Sigma^+$ allows a test of exotic exchange contributions for $t \neq 0$ and no significant discrepancy is found. In particular the exotic exchange amplitudes are constrained to be smaller than the observed line reversal equality violating amplitudes.

e) - Polarization

The data ³⁾ are shown in Fig. 2. The $\pi^+ p \rightarrow K^+ \Sigma^+$ data show no pronounced dependence on energy between 3 and 14 GeV/c. We shall assume that the other reactions also have polarizations approximately constant with energy. From SU(3) considerations ⁷⁾, the polarization is expected to change sign under $\Lambda \rightarrow \Sigma$ interchange and Fig. 2 shows that this is clearly supported by the data. $P(\pi^- p \rightarrow K^0 \Lambda^0)$ and $-P(\pi N \rightarrow K \Sigma)$ are zero near $t \sim -0.3 \text{ GeV}^2$

^{*)} The 8 and 16 GeV/c data from Birnbaum et al. have been renormalized by 0.66. Evidence is : i) simultaneous α_{eff} fits at several fixed t values to these data, together with all other $K^- p \rightarrow \pi^- \Sigma^+$ data, suggest a renormalization of 0.66 for consistency ; ii) the $\pi^- p \rightarrow p \pi^-$ data from the same experiment at the same energies need ⁶⁾ a renormalization of ~ 0.66 to agree with other $\pi^- p \rightarrow p \pi^-$ data.

and are ≈ -1 for $t \lesssim -0.6 \text{ GeV}^2$. $P(\bar{K}N \rightarrow \pi \Lambda)$ and $-P(\bar{K}N \rightarrow \pi \Sigma)$ rise to near $+1$ for $t \sim -0.3 \text{ GeV}^2$ and remain large. Note that if $|P| = 1$ the spin decomposition is known and no further information is obtained from R and A parameter measurements.

COMPARISONS

a) - The effective Regge pole

The effective Regge pole approaches would not explain naturally the difference between the α_{eff} values for $\pi N \rightarrow KY$ and $\bar{K}N \rightarrow \pi Y$, the latter having a rather small slope. The polarization averages $^{*)} P_{\Lambda}^{(+)}$ and $P_{\Sigma}^{(+)}$ are non-zero experimentally and, since they arise only from interference between poles of the same signature, this implies the presence of at least three Regge poles, or two complex poles. The complex Regge pole approach $^{8)}$ can yield naturally an explanation of the inequality of cross-sections under crossing, but this is apparently the only prediction that can be made. No simple over-all picture emerges.

b) - The Michigan model

The Michigan model has α_{eff} values at large t which are rather flat and would accommodate the $\bar{K}N \rightarrow \pi Y$ data although not the data for $\pi N \rightarrow KY$. Some dip structure in the latter reaction could be obtained from pole-cut cancellation. The inequalities in line-reversed cross-sections can be accommodated since the model is flexible, even too flexible unless the systematics $^{1)}$ of zeros near -0.2 and -0.6 in helicity non-flip and flip amplitudes are added.

$^{*)}$ We define $P_{\Lambda}^{(+)} = (P_1 d\sigma_1/dt + P_2 d\sigma_2/dt)/(d\sigma_1/dt + d\sigma_2/dt)$ where 1 and 2 refer to $\pi^- p \rightarrow K^0 \Lambda^0$ and $K^- n \rightarrow \pi^- \Lambda^0$ respectively; and similarly for $P_{\Sigma}^{(+)}$. Data near $4 \text{ GeV}/c$ show $P_{\Lambda}^{(+)}$ positive at about 0.3 with no sign change for $-0.1 > t > -1.0$. In any t channel model $P_{\Lambda}^{(+)}$ or $-P_{\Sigma}^{(+)}$ are similar theoretically to the polarization P in $\pi^- p \rightarrow \pi^0 n$ and in $\pi^- p \rightarrow \eta^0 n$ and thus provide an empirical prediction for the latter reactions.

Then polarization P and R , which are bilinear products [we define $R d\sigma/dt = \text{Re}(F_{++} F_{+-}^*)$] of flip and non-flip amplitudes, should be zero at these t values. Berger and Fox have emphasized ²⁾ that the zero of R near -0.3 is a general consequence of the Michigan model ; however, their prediction for the $\bar{K}N \rightarrow \pi Y$ polarization is too small. Indeed, it would seem natural to obtain small polarization near -0.2 and -0.6 in a Michigan model fit in contrast to the data which show $|P| \sim 1$ at $t \sim -0.6$.

c) - The absorptive cut model based on E.X.D. poles

The absorptive cut model based on E.X.D. poles is much more specific and successfully predicts ⁹⁾ both the signs and the zeros of the polarization data. We performed quantitative fits to all the available high-energy $\bar{K}N \rightarrow \pi Y$ forward data and used the resulting parameters to compare our predictions for $\pi N \rightarrow KY$ with data.

We parametrized the $K^* - K^{**}$ E.X.D. pole contributions to the s channel helicity non-flip ($n=0$) and flip ($n=1$) amplitudes in the form

$$F_n = (t_{\min} - t)^{n/2} \gamma_n^{1, \Sigma} e^{R_n t} (s e^{i\phi})^{\alpha(t)}$$

with units $\hbar = c = \text{GeV} = 1$ and normalization such that

$$d\sigma/dt = \{ |F_0|^2 + |F_1|^2 \} / 64\pi^2 s$$

We took a real $\bar{K}N \rightarrow \pi Y$ amplitude ($\phi = 0$) and a rotating phase $\pi N \rightarrow KY$ amplitude ($\phi = -\pi$) as duality diagrams predict. These were absorbed with a Pomeron of trajectory $1 + 0.5 t$ and cross-section dependence of e^{8t} with an effective total cross-section (real or rotating ; Σ or Λ ; initial or final) of $30 \lambda_n$ mb. The Pomeron trajectory slope ¹⁰⁾ is essential to avoid a deep dip in $d\sigma/dt$ and zero polarization for $\bar{K}N \rightarrow \pi Y$. The prescription of averaging the absorbing cross-section over both line-reversed reactions as well as

over initial and final states is necessary to preserve the Regge cut signature as the product of the pole and Pomeron signatures. Then λ_n is the same for $\pi N \rightarrow KY$ and $\bar{K}N \rightarrow \pi Y$ and the difference in the description of the Σ and Λ data arises only from the parameters γ_n . Moreover, there is evidence that the absorptive cuts contribute little to single helicity flip amplitudes. The double zero in $P(\pi^- p \rightarrow \pi^- p) - P(\pi^+ p \rightarrow \pi^+ p)$ at $t = -0.6$ and the observed shrinkage in $d\sigma/dt$ ($\pi^- p \rightarrow \pi^0 n$) are both better described with poles alone in the helicity flip amplitudes. Thus we set $\lambda_1 = 0$.

The resulting fit to the $\bar{K}N \rightarrow \pi Y$ cross-sections and polarizations above 4 GeV/c yields the following parameter values :

$$\begin{aligned} \gamma_0^{\Sigma^0} &= 42.1 & \gamma_0^{\Lambda} &= 47.3 & R_0 &= 1.07 & \alpha(t) &= 0.4 + 0.8t \\ \gamma_1^{\Sigma^0} &= 17.0 & \gamma_1^{\Lambda} &= -33.0 & R_1 &= 0.77 & \lambda_0 &= 1.2 \end{aligned}$$

The parameter values are very reasonable and the quality of the fit is excellent. The break in $d\sigma/dt$ at $t \sim -0.4$ is accounted for by the flatter cut contributions dominating beyond that t value, and α_{eff} is well described (Fig. 1). Figure 2 shows the polarization fits and also the predictions for R with a sign change at $t \sim -0.5$. This R prediction is qualitatively similar to that from the Michigan model.

For the $\pi N \rightarrow KY$ data, our polarization predictions are astonishingly good while for the $d\sigma/dt$ data, our predictions are only reasonable asymptotically. Since λ_0 was taken the same for all processes we have more absorption ¹¹⁾ for $\bar{K}N \rightarrow \pi Y$ (real phase) than $\pi N \rightarrow KY$ (rotating phase). Figure 1 shows the resulting larger $\pi N \rightarrow KY$ cross-section (dashed line) which is only compatible with data at high-energies and small momentum transfers. At lower energies for $\pi N \rightarrow KY$ the cut corrections to $d\sigma/dt$ are in the wrong direction relative to the data. We shall discuss latter possible non-asymptotic contributions to remedy this situation.

Finally we comment that the $SU(3)$ expectations ⁷⁾ for $K^* - K^{**}$ couplings to $N\Sigma$ and $N\Lambda$ are fulfilled naturally. The ratios $\gamma^{\Sigma^0} / \gamma^{\Lambda} = \sqrt{3}(F-D)/(3F+D)$ and so yield $F/D = -2.8$ and 0.38 for $n = 0$ and 1 . These F/D ratios are compatible with all other evidence ⁷⁾ and thus the absolute signs of our polarization calculations are in agreement.

NON-ASYMPTOTIC CONTRIBUTIONS

We have noted earlier that the line-reversal equality violating amplitudes are empirically much larger than those for exotic exchange. With this constraint in mind we discuss two approaches.

a) - Regge-Regge cuts

Regge-Regge cuts have been considered ^{11), 12)} as an explanation for the line-reversal inequalities in KN and $\bar{K}N$ charge exchange although Finkelstein ¹³⁾ has questioned the validity of the approach. For our $K^* - K^{**}$ exchange processes the Regge-Regge cut contributions do not seem to give naturally ¹¹⁾ the correct sign of the effect and would also contribute comparably to exotic t channel amplitudes.

b) - s channel resonances

s channel resonances also contribute in general as much to line-reversal splitting as to exotic exchange amplitudes. However, the resonance contributions are correlated through duality considerations. The resonances in $\pi^- p \rightarrow K^+ \Sigma^-$ (also the resonances in $K^- p \rightarrow \pi^+ \Sigma^-$) must be exchange degenerate and cancel in the forward direction. For the other $\bar{K}N \rightarrow \pi Y$ amplitudes, the $Y_0^* - Y_1^*$ resonances are also supposed to be exchange degenerate for a duality diagram argument and this has been checked empirically ¹⁴⁾ for the leading resonances at $t = m_K^2$. At low energies, however, the quantity $V(s, t) = d\sigma/dt (\bar{K}N \rightarrow \pi Y) - d\sigma/dt (\pi N \rightarrow KY)$ would only be small if the $Y = 0$ and $Y = 1$ resonances were closely correlated. The

leading $Y_0^* - Y_1^*$ resonances contribute empirically a substantial $\bar{K}N \rightarrow \pi Y$ cross-section whereas the $N - \Delta$ resonances contribute much more weakly to $\pi N \rightarrow KY$. Furthermore, at the same energy the leading $N - \Delta$ trajectories have higher angular momentum than the leading $Y_0^* - Y_1^*$ trajectories since the latter have lower intercepts. This higher ℓ for $N - \Delta$ trajectories implies a steeper t dependence if they dominate the cross-section. The s channel leading resonances thus give a violation of line-reversal equality with the $Y_0^* - Y_1^*$ states being stronger and of flatter t dependence than the $N - \Delta$ states. This is the same as the breaking observed at higher energies (3-8 GeV/c). Furthermore, at $t = m_{K^*}^2$, the K^* pole should dominate even at intermediate energies and give $V = 0$. The trend of the data is in accord since the relative line-reversal inequality decreases with $|t|$ towards $t = 0$ and could be negligible at $t = m_{K^*}^2$. Note also that since the $Y_0^* - Y_1^*$ resonances are stronger for $t \lesssim 0$ than the $N - \Delta$ resonances, we can explain the ratio of $d\sigma/dt (K^-p \rightarrow \pi^+\Sigma^-)$ to $d\sigma/dt (\pi^-p \rightarrow K^+\Sigma^-)$ which is about 10 below 4 GeV/c.

In order to proceed further we remark that in a Veneziano model with pole-pole duality, the daughter contributions at low energy would be such as to yield a correlation between $Y = 0$ and 1 resonances so that $V \approx 0$. Thus empirically the daughter contributions (low ℓ states) should be suppressed relative to a Veneziano model. Our absorbed E.X.D. pole model is, however, essentially a dual model with low ℓ suppressed. Thus for $\bar{K}N \rightarrow \pi Y$ which has a mainly real amplitude, our model should be reliable even to low energies. On the contrary, for $\pi N \rightarrow KY$, one should modify the absorption in a non-asymptotic way at lower energies to reproduce the leading resonance dominance in the imaginary part of the amplitude. Such a duality between effective high-energy models and the leading low-energy resonances then provides an insight into the difference of behaviour between $\bar{K}N \rightarrow \pi Y$ and $\pi N \rightarrow KY$ at lower energies.

CONCLUSIONS

The data on hypercharge-exchange reactions show an approach with increasing energy to equality between the line-reversed cross-sections. The data on the "real" reactions $\bar{K}N \rightarrow \pi Y$ are in excellent accord with an absorbed E.X.D. $K^* - K^{**}$ pole model. This model has very reasonable parameters and has the absorption enhanced in the s channel non-flip amplitudes and suppressed in the flip amplitudes. The large polarization is naturally described by the model in contrast to other models. We present predictions for R which are qualitatively similar to those from the Michigan model. From consideration of the empirical low-energy resonance features we anticipate modifications in the imaginary parts at lower energies. Then, non-asymptotic contributions to the rotating phase reactions $\pi N \rightarrow KY$ will be substantial and are not included in our asymptotic model. Instead we note the empirical continuity that the resonance region amplitudes carry their ratios ($Y = 0$ to $Y = 1$) and t dependent structure to higher energies.

Further data on the structure and energy dependence of the line-reversal inequalities and of the exotic exchange contributions would be welcome. Polarization, R and A data at high energies will also be very useful for further analysis of the hypercharge exchange reactions.

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FIGURE CAPTIONS

Figure 1 Differential cross-sections for $K^-p \rightarrow \pi^- \Sigma^+$ and $\pi^+p \rightarrow K^+ \Sigma^+$ against energy at fixed t values of -0.1 , -0.3 and -0.6 GeV^2 . $K^-p \rightarrow \pi^- \Sigma^+$ data ³⁾ are shown by circles, and $\pi^+p \rightarrow K^+ \Sigma^+$ data ^{3),4)} with stars and with squares to denote the preliminary Bashian et al. data. Relative to the $K^-p \rightarrow \pi^- \Sigma^+$ data, the $\pi^+p \rightarrow K^+ \Sigma^+$ data shrink faster, are smaller at low energies, and approach equality around $10 \text{ GeV}/c$. The result of our E.X.D. pole absorption fit to $\bar{K}N \rightarrow \pi \Sigma$ data above $4 \text{ GeV}/c$ is shown by the continuous curves. The predictions for $\pi^+p \rightarrow K^+ \Sigma^+$ of the same fit are shown by the dashed lines which only lie close to the data at higher energy and smaller t .

Figure 2 Polarization P and the parameter R for $\bar{K}N \rightarrow \pi \Sigma(\Lambda)$ and $\pi N \rightarrow K \Sigma(\Lambda)$ against t . A selection of data is shown ³⁾. The continuous curves show the result of our E.X.D. pole model at $s = 11 \text{ GeV}^2$. The $\bar{K}N \rightarrow \pi \Sigma(\Lambda)$ polarization data were fitted while the R values and $\pi N \rightarrow K \Sigma(\Lambda)$ polarization are predicted.

FIG. 1

FIG. 2