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DUAL + POMERON ANALYSIS OF $K^{\pm}p \rightarrow K^{\pm}\pi^0p$

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A B S T R A C T

Data for $K^{\pm}p \rightarrow K^{\pm}\pi^0p$ are analyzed in terms of a model containing a dual five-point amplitude added to a model amplitude for the diffraction dissociation process $K^{\pm}p \rightarrow K^{\pm}N^*$. The magnitudes of these amplitudes are estimated by connecting them to those of previously analyzed $KN \rightarrow K\pi N$ reactions by isospin and by factorization, respectively. Clear evidence for a considerable ($\approx 50\%$ at 10 GeV/c) Pomeron contribution is found and a satisfactory over-all description of the data is given. The reasons for the discrepancies on a detailed level are inherent to the model.

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1. INTRODUCTION

Consider the set of reactions $KN \rightarrow K\pi N$ together with all the reactions obtained from this by crossing. These can be divided ¹⁾ in different classes, so that within one class all reactions are related to each other by charge conjugation, crossing, or charge symmetry. Full isospin symmetry is needed to connect different classes. According to the dominant dynamical mechanisms, the three main classes can also be characterized as follows :

- (I) ω coupling to $N\bar{N}$ and Pomeron coupling to $K\bar{K}$
- (II) ω coupling to $N\bar{N}$
- (III) π coupling to $N\bar{N}$ and Pomeron coupling to $K\bar{K}$

with the prototype reactions

$$\begin{aligned} \text{(I)} \quad & K^+ p \rightarrow K^+ \pi^0 p & (1.1) \\ & K^- p \rightarrow K^- \pi^0 p & (1.1') \end{aligned}$$

$$\begin{aligned} \text{(II)} \quad & K^+ p \rightarrow K^0 \pi^+ p & (1.2) \\ & K^- p \rightarrow \bar{K}^0 \pi^- p & (1.2') \end{aligned}$$

$$\begin{aligned} \text{(III)} \quad & K^+ p \rightarrow K^+ \pi^+ n & (1.3) \\ & K^- p \rightarrow K^- \pi^+ n & (1.3') \end{aligned}$$

In Ref. 1), reactions of class (II) were analyzed in a crossing symmetric fashion with a model based on the dual five pion function ²⁾; Ref. 3) treats in a similar way the reaction channel (1.2') ⁴⁾. The purpose of this paper is to carry out an analysis of class (I) reactions, which are

more complicated because of the presence of Pomeron coupling to the $K\bar{K}$ channel or diffraction dissociation of the initial p to $I=\frac{1}{2}$ πN states (Fig.1).

According to current ideas about duality Pomeron exchange in the t channel is dual to the background of the resonances in the s channel and thus has no place in a dual resonance model. We therefore apply (Section 2) to Pomeron exchange a model given in Ref. 6), which treats the Pomeron exchange in a non-dual manner but inserts a dual resonance model for the pion pomeron production part of the amplitude (Fig.1). This amplitude A_P is added to a sum A_V^I of dual five-point amplitudes constructed (Section 3) according to the principles of Ref. 1) (Fig.2). In a sense this model has no free parameters since the inherent parameters of A_P and A_V^I are determined by analyses of $pp \rightarrow p \pi^+ n$ and class (II) reactions, respectively, and since their magnitudes can be determined by factorization 7) and by isospin relations between reactions of class (I) and (II).

Due to the presence of the π^0 , the experimental data 8),9) for class (I) reactions are much scarcer and of worse quality than those for class (II). In particular, there are no data for reaction (1.1) at above 3.5 GeV/c. Thus the present analysis can be considerably improved and constrained with better data. Also, for class (I) reactions with πN or $N\bar{N}$ initial states, to which the Pomeron would not contribute, there is no or hardly any data. We shall omit these entirely from consideration.

Since class (I) reactions are symmetric under crossing of the π^0 , the trajectories to be included in the dual amplitude are more strongly constrained than those of class (II) reactions. The trajectories included in Ref. 1) are not compatible with these constraints and isospin and we have to modify their amplitude for class (II) by changing some of the trajectories. This does not change the over-all quality of the fits to class (II) reactions, although in some cases one is led to a worse agreement with experiment. In general, with a strongly constrained amplitude, the inherent difficulties of the model are very obvious. The main one of these, as emphasized in Ref. 3), is the impossibility of including within one dual amplitude more than one trajectory coupling to a definite two-particle channel. This would necessitate the introduction

of additional terms, a solution which we avoid in the present work for the sake of simplicity. This restriction is only temporary and should be eliminated before the full potentialities of the model can be evaluated. So far the present results are basically only accurate to the extent that different trajectories coupling to the same channel are degenerate.

2. THE POMERON CONTRIBUTION

In the reactions $K^\pm p \rightarrow K^\pm \pi N$ the final πN system may be produced by diffraction dissociation or Pomeron exchange from the initial proton (Fig.1). This restricts the quantum numbers of the πN system to be those of the proton apart from spin and parity changes and leads to an asymptotically constant reaction cross-section. The observed rapid energy dependence of K^* production cross-sections ¹⁰⁾ is an evidence against a similar mechanism in the production of $K\pi$ systems.

Since there exist no data on $K^\pm p \rightarrow K^\pm \pi N$ for $p_{\text{lab}} > 10 \text{ GeV/c}$ we estimate without any detailed model the amount of Pomeron exchange from high energy data for $pp \rightarrow p\pi N$ by assuming the Pomeron couplings to be factorizable ⁷⁾. Satz ¹¹⁾ has estimated from all available pp data that for $s \rightarrow \infty$ $\sigma_{\text{as}}(pp \rightarrow p\pi^+n) = 1.2 \text{ mb}$ giving by isospin $\sigma_{\text{as}}(pp \rightarrow p\pi^0p) = 0.6 \text{ mb}$. One then has

$$\sigma_{\text{as}}(K^\pm p \rightarrow K^\pm \pi^+n) = \left[\frac{\sigma_{\text{as}}^{\text{tot}}(KP)}{\sigma_{\text{as}}^{\text{tot}}(PP)} \right]^2 \sigma_{\text{as}}(pp \rightarrow p\pi^+n) \approx 0.22 \text{ mb.}$$

and $\sigma_{\text{as}}(K^\pm p \rightarrow K^\pm \pi^0p) \approx 0.11 \text{ mb}$. These numbers are to be compared with ¹²⁾ $\sigma_{\text{exp}}(K^-p \rightarrow K^- \pi^+n) = 0.35 \pm 0.014 \text{ mb}$ and $\sigma_{\text{exp}}(K^-p \rightarrow K^- \pi^0p) = 0.28 \pm 0.02 \text{ mb}$ at 10 GeV/c . Thus qualitatively a considerable amount ($\approx 50\%$ of the total at 10 GeV/c) of Pomeron exchange (σ_P) is to be expected. This amount can also be bounded from above by assuming that $K^\pm p \rightarrow K^\pm \pi^+n$ is all Pomeron. Then $\sigma_P(K^\pm p \rightarrow K^\pm \pi^0p) \leq \frac{1}{2} \sigma_{\text{exp}}(K^-p \rightarrow K^- \pi^+n)$ so that at 10 GeV/c $\sigma_P(K^-p \rightarrow K^- \pi^0p) \leq 0.18 \text{ mb}$.

In order to make more quantitative statements, we shall use the following amplitude (Fig.1) for the Pomeron exchange contribution to $KN \rightarrow K\pi N$ ($s_0 = 1 \text{ GeV}^2$):

$$A_P = g_P \left(\frac{s_{ab}}{s_0} \right)^{2t_{a1}} \sqrt{\frac{-t_{b3}}{s_0}} A(s_{23}, t_{b3}) \quad (2.1)$$

where A is a dual model amplitude for pion pomeron production given in Ref. 6). Its parameters are fixed by an analysis of $pp \rightarrow p\pi^+n$ at 28.5 GeV/c and we take them unchanged from Ref. 6). The main properties of A_P are :

- the $\bar{p}p$ channel in A couples to the pion giving rise to the kinematical factor $\sqrt{-t_{b3}/s_0}$;
- the πN channels in A couple to the N_α [containing the nucleon and the $N(\frac{5}{2}^+, 1688)$] and to the N_γ [containing the $N(\frac{3}{2}^-, 1520)$], assumed here to be non-degenerate. The πN mass spectrum arising from A contains on a large ($\approx 80\%$) and sharp background from π exchange two clear nucleon resonances at masses 1.35 ($\frac{1}{2}^+$ daughter of N_α) and 1.52 ($\frac{3}{2}^-$ pole of N_γ). Since N_α is very well determined, it is difficult to increase the mass 1.35 to values larger than 1.4, where a resonance is normally seen in production experiments;
- the $\bar{K}K$ Pomeron residue function $e^{2t_{a1}}$ is obtained from $\bar{K}p$ elastic scattering through factorization;
- the reaction cross-section (F is a flux factor)

$$\sigma_P = \frac{F}{P_{\text{Lab}}} \int \prod_{i=1}^3 \frac{d^3 p_i}{2E_i} \delta^4(p_a + p_b - p_1 - p_2 - p_3) |A_P|^2 \quad (2.2)$$

arising from A_P behaves as shown in Fig. 3. The initial rapid rise at $p_{\text{lab}} \approx 2 \text{ GeV/c}$ is due to the opening of the channel $Kp \rightarrow KN^*$ where N^* lies within the sharp diffraction dissociation peak at $m_{\pi N} \approx 1.5 \text{ GeV}$. Above 3 GeV/c σ_P increases slowly approaching its asymptotic value σ_{as} from below;

- e) P is a spin non-flip term in the sense that the distributions in t_{a1} and t_{b3} are strongly peaked for small values of these variables ($\sqrt{-t_{b3}}$ causes a turn-over at $t_{b3} \sim m_{\pi}^2$). Thus its interference with the dual term which is mainly spin flip, Eq. (3.1), is negligible and its phase is irrelevant for present purposes;
- f) the $K\pi$ and Kp mass spectra, as given by A_P , are structureless and examples of them are shown in Figs. 4-6.

3. THE DUAL CONTRIBUTION

In order to determine the dual part of the amplitude, one has to solve two problems : 1) determine the dominant trajectories coupling to different two-particle channels in the diagrams of Fig. 2; 2) determine the linear combination in which the model amplitudes corresponding to the diagrams of Fig. 2 appear. There is within the present framework no unique solution to either one of these problems. We shall make a choice of the trajectories in the ambiguous cases on the basis of what resonances are seen to be produced in class (I) reactions and determine the linear combination by choosing a fixed initial state (K^+p) and by using isospin relations between classes (I), (II) and (III).

Considering first the choice of trajectories, Fig. 2 shows three of the four diagrams not containing exotic channels. The fourth one, corresponding to a non-planar duality graph and differing from P by an interchange of K and π , is excluded ¹⁾ by K^* and K^{**} exchange degeneracy (EXD). Each graph corresponds to a model amplitude with a kinematical factor and B_5 function. For a treatment of these as well as for the detailed forms of the trajectory functions we refer to Ref. 1).

Due to the symmetry of class (I) reactions, the choice of trajectories is more restricted than for class (II) reactions. From Fig. 2 one sees that under charge conjugation P and R are interchanged and S

goes into itself (note the symmetry of S around π^0). This requires that the same trajectories are to be used in P and R and that the two K^-p channels in S couple to the same trajectories, similarly the two π^0p channels. If, e.g., the two K^-p channels in S contained different trajectories, C invariance would require the introduction of another S graph with the roles of the two trajectories interchanged, which in turn, when coupled with EXD arguments, would induce the doubling of P and R graphs, too. This possibility was excluded in the present work, but will have to be considered if the model is further refined.

There is no reasonable alternative to the trajectories A_2 , K^* and ω coupling to $K\bar{K}$, $K\pi$ and $p\bar{p}$, respectively. The amount of π coupling to $p\bar{p}$ in class (I) reactions can be seen to be small by the following argument. Assume that one half of the 0.35 mb of class (III) $K^-p \rightarrow K^- \pi^+ n$ at 10 GeV/c is given by π exchange producing $I=\frac{1}{2}$ $K\pi$ states (the other half being Pomeron exchange). Isospin then gives an estimate, probably an upper bound, of 0.04 mb of π exchange in $K^-p \rightarrow K^- \pi^0 p$, which will be neglected ^{*)}.

The serious problem lies in the choice of trajectories coupling to the K^-p and the π^0p channels. Consider first the K^-p channel. Experimentally, one knows ^{13),14)} that there are two trajectories coupling strongly to $\bar{K}N$, the $I=0$ EXD $\Lambda_\alpha - \Lambda_\gamma$ trajectory [with $\alpha_\Lambda(t) \approx -0.68 + 0.9t$ and containing $\Lambda(\frac{1}{2}^-, 1115)$ and $\Lambda(\frac{5}{2}^-, 1520)$] and the $I=1$ EXD $\Sigma_\rho - \Sigma_\delta$ trajectory [with $\alpha_Y(t) \approx -0.22 + 0.9t$ and containing $Y_1(\frac{3}{2}^+, 1385)$ and $Y_1(\frac{7}{2}^+, 1765)$].

There is no reason to expect that their couplings to $\bar{K}\pi N$ are so different that only either one of them would dominate. Thus both have to be included in general, which is impossible in the present framework without introducing a large number of dual five-point functions. Thus an analysis limiting itself to the three diagrams in Fig. 2 can only be expected to be valid to the accuracy α_Λ and α_Y are degenerate.

*) Notice, however, that the Pomeron term (2.1) contains π exchange and thus simulates the momentum transfer dependence of the dual π exchange contribution.

Similar remarks with some additional complications apply to the $\pi^0 p$ channel. This couples strongly either to the EXD $\Delta_{S-N\beta}$ trajectory Δ (with $\alpha_\Delta(t) \approx 0.12 + 0.9t$) or to the EXD $N_{\alpha-N\gamma}$ trajectory N (with $\alpha_N(t) \approx -0.37 + t$). Notice, in particular, that the $3/2^+$ decuplet is EXD with a $5/2^-$ octet (so that Δ^{++} has no EXD $5/2^-$ partner) and that the $1/2^-$ component of α_Δ is experimentally absent. This implies ¹⁵⁾ a zero in the residue function at $\alpha_\Delta = \frac{1}{2}$ which is missing in the present model and may be related to the problems with Δ^{++} production in Ref. 1). Again it is obvious that both Δ and N should be included, but one has to choose either one. We choose the trajectories as shown in Fig. 2 for the following reasons :

- a) Λ is taken in the $K^- p$ channel since it is clearly produced in class (I) $K^- p$ reactions while the signal for Y in $K^- p \rightarrow \bar{K}^0 \pi^- p$ is very weak;
- b) Δ is taken in the $\pi^0 p$ channel since it is clearly produced in both class (I) and (II) reactions and since the Pomeron exchange, in any case, produces $I = \frac{1}{2}$ πN states.

Turning then to the problem of determining the linear combination of the amplitudes, we can first, with the trajectories chosen, write the analytic forms of the amplitudes as in Ref. 1). Since charge conjugation interchanges P and R the total amplitude for class (I) reactions has to be of the form

$$A_V^I = g_V [P + R + \beta S] \quad (3.1)$$

Here P , R and S each contain an appropriate B_5 function multiplied by the kinematical factor $\epsilon_{\mu\nu\sigma\rho} p_a^\mu p_1^\nu p_2^\sigma p_3^\rho$ accounting for the spin flip character of A_V^I . The value of β depends on the EXD properties of the trajectory coupling to $\pi^0 p$; exact $\Delta_{S-N\beta}$ EXD requires $\beta = 0$.

In order to determine β we use the isospin relations between different classes of reactions, in particular the $K^+ p$ reactions (1.1)-(1.3). Write for the amplitudes of these reactions :

$$\begin{aligned}
 A_V^I &= g_V [P + R + \beta S] \\
 A_V^{II} &= g'_V [P + \alpha(R + S)] \\
 A_V^{III} &= -\sqrt{2} A_V^I - A_V^{II}
 \end{aligned}
 \tag{3.2}$$

where R and S in A_V^{II} have the same coefficient since they differ by a permutation of π^+ and p and the Δ^{++} has very clearly no $\frac{5}{2}^-$ EXD partner. The last equation in (3.2) is a general isospin relation.

Consider first K^* production, which only comes from the P graph. Since there are no $I = \frac{3}{2}$ $K\pi$ resonances, there can be no P graph in A_V^{III} and $g_V^I = -\sqrt{2} g_V$. Consider the Δ production coming from R and S graphs. Isospin gives for the ratio of the Δ production amplitudes in reactions (1.1) and (1.2) the value $-\sqrt{2}/3$; (3.2) gives for the same ratio the value $(1 + \beta)/(-2\sqrt{2}\alpha)$. If $\alpha \neq 1$ the R graph appears in the amplitude for class (III) reactions, implying an exotic $K\pi$ state in class (III) K^-p reactions. Thus $\alpha = 1$ so that $\beta = 1/3$ and

$$\begin{aligned}
 A_V^I &= g_V [P + R + \frac{1}{3} S] \\
 A_V^{II} &= -\sqrt{2} g_V [P + R + S] \\
 A_V^{III} &= \frac{2\sqrt{2}}{3} g_V S
 \end{aligned}
 \tag{3.3}$$

We note the following points :

- a) $\Delta_{\delta-N\beta}$ EXD is slightly broken, since $\beta \neq 0$. This does not violate present experimental data.
- b) For the K^-p reactions (1.1') and (1.2'), (3.3) predicts correct K^* branching ratios but a ratio $-\sqrt{2}/3$ of the Δ production amplitudes instead of the value $-\sqrt{2}$ corresponding to a pure $I = \frac{3}{2}$ Δ . Experimentally this ratio squared is larger than 1 so that (3.3) will predict too much Δ

production in (1.2'). Imposing the correct branching ratio here and solving for β and α gives $\beta = -5$, $\alpha = -3$, which are quite unreasonable values. In Ref. 1) this difficulty with Δ production was eliminated by using the N trajectory instead of Δ in the πN system produced in K^-p reactions. Here both C invariance and isospin make this impossible - unless one either uses more diagrams or takes N and Δ to be degenerate. Similarly, the $\bar{K}N$ system 13 in R and S couples to the Λ in (3.3), while it is $\bar{K}^0p$ in class (II) and only couples to Y. Thus one is bound to get disagreements in the mass spectra in either class (I) or (II) reactions, if both are treated simultaneously with only three graphs.

- c) In class (III) reactions, the only contribution comes from the S graph, which does not contain any trajectory coupling to a $p\bar{p}$ system. Thus in an analysis of class (III) reactions the contribution of vector exchange S can be estimated from the present treatment and added to the π and Pomeron contributions.
- d) If one assumes that the Λ and Y trajectories represent pure isospins 0 and 1, respectively, the S in which either Λ (Fig.2) or Y appears symmetrically in agreement with the requirements of charge conjugation violates isospin conservation. This can be seen by going simultaneously to the two K^-p poles in S. Then the couplings to the π^0 are of the forms $\Lambda\pi^0\bar{\Lambda}$ or $Y\pi^0\bar{Y}$, which vanish by isospin if Λ or Y are pure $I=0$ and 1 states. These couplings can be made non-vanishing if the Λ is degenerate with some $I=1$ trajectory [possibly the EXD $\Sigma_\alpha - \Sigma_\gamma$ trajectory containing $\Sigma(\frac{1}{2}^+, 1190)$ but coupling weakly to $\bar{K}N$] and the Σ degenerate with some $I=0$ trajectory.

4. COMPARISON WITH EXPERIMENTAL DATA

The matrix element for class (I) reactions is now $A^I = A_V^I + A_P^I$. Since the interference between the two amplitudes is negligible, the predictions of the model for a distribution $D^I(i)$ in the set of variables (i) can be written as

$$D^I(i) = \frac{F}{P_{Lab}} \left[g_V^2 \langle V^I(i) \rangle + g_P^2 \langle P(i) \rangle \right] \quad (4.1)$$

In (4.1) $g_V^2 \langle V^I(i) \rangle$ and $g_P^2 \langle P(i) \rangle$ are the numbers obtained by performing the phase space integrations of $|A_V^I|^2$ and $|A_P|^2$ over all variables apart from those in (i). Integrating over all the variables one obtains the numbers $\langle V^I \rangle$ and $\langle P \rangle$ and from (4.1) the total reaction cross-section σ^I .

The coupling constant g_V of the dual term in (4.1) is determined so that A_V^{II} in (3.3) gives for the reaction cross-section of class (II) reaction $K^-p \rightarrow \bar{K}^0 \pi^- p$ the measured ¹²⁾ value 0.22 ± 0.02 mb at 10 GeV/c. With $\langle V^{II} \rangle = 0.28 \text{ GeV}^2$ at 10 GeV/c, one finds $Fg_V^2 = 8.5$ mb. The dual vector exchange contribution to class (I) reaction $K^-p \rightarrow K^- \pi^0 p$ is then by (4.1) approximately $\sigma^I = 0.11$ mb (with $\langle V^I \rangle = 0.13 \text{ GeV}^2$) out of a measured ¹⁰⁾ total of 0.28 ± 0.02 mb. Including a Pomeron contribution with the magnitude 0.11 mb as estimated on the basis of factorization (Section 2), leaves 0.07 mb unaccounted for, indicating the possible presence of other contributions (π exchange, production of resonances not appearing in Fig. 2, other spin terms, etc.). However, since there is at present no way to disentangle these contributions, we simulate them by fixing the magnitude of the Pomeron term to be 0.17 mb, corresponding to $Fg_P^2 = 0.0013$ mb (with $\langle P \rangle = 1300$). If one does not want to use the factorizability of the Pomeron, this value is also obtained by fitting the data for one-particle distributions at 10 GeV/c with an expression of the form (4.1).

With g_V and g_P thus determined the model gives definite predictions at all energies for $K^-p \rightarrow K^- \pi^0 p$ and, by crossing, under which the Pomeron contribution is invariant, for $K^+p \rightarrow K^+ \pi^0 p$. Predictions for total reaction cross-sections and mass and momentum transfer distributions are shown in Figs. 3-6. All calculations have been carried out by Monte Carlo methods and the histograms obtained smoothed by hand. The contributions of the various graphs appear for $p_L \gtrsim 3 \text{ GeV/c}$ roughly in the ratios $P^2 : R^2 : S^2 = 10 : 3 : 1$ for K^+p and $10 : 5 : 2$ for K^-p .

The total cross-sections have a reasonable high energy behaviour but are too low by a factor 2 at the maximum cross-section when $p_{\text{lab}} \approx 1.5 \text{ GeV/c}$. This is to be expected since the kinematical factors in (3.3) were constructed on the basis of an ω exchange mechanism dominant at high energies. At lower energies other mechanisms dominate, e.g., the reaction (1.1') proceeds rather through the chain ¹⁶⁾
 $K^-p \rightarrow Y_1(\frac{7}{2}^+, 1765) \rightarrow \Lambda(\frac{5}{2}^-, 1520) \pi^0$ not included in the present treatment and giving rise to another kinematical factor.

The low energy structure in K^-p reactions is due to the input Λ resonances in the incoming K^-p system in the P and S graphs. No such structure is seen experimentally. Changing the Λ into a Y changes both the shape and size of the low energy cross-sections considerably. As both of these are known to contribute, the model is clearly reliable only beyond the resonance region, $p_{\text{lab}} \gtrsim 3 \text{ GeV/c}$.

Figure 3 also gives the magnitude of vector exchange ϕ_V^{III} as predicted by Eq. (3.3). This can be seen to be less than 10% of the measured class (III) cross-sections.

The distributions in $M(K^- \pi^0)$ for $K^-p \rightarrow K^- \pi^0 p$ show consistently too strong K^* production. This is at least partly due to low experimental resolution since, e.g., in the 10 GeV/c data the K^* peak is wider than expected of a K^* with established width. In fact, 19% of the events lie in the band $0.8 < M(K^- \pi^0) < 1.0$ the corresponding theoretical number being 23%, in satisfactory agreement. In the $M(\pi^0 p)$ spectrum, one can see too strong $N^*(1520)$ production at 10 GeV/c. This could be adjusted by a parameter in the Pomeron exchange amplitude ⁶⁾. The peak at large values of $M(p \pi^0)$ is at least partly due to misidentified events from the channel $K^-p \rightarrow K^- \pi^0 \pi^0 p$; its domination would increase K^* and decrease K^{**} production.

The distributions in $t_{K^-K^-}$ and t_{pp} for $K^-p \rightarrow K^- \pi^0 p$ are shown in Fig. 6. Due to the presence of π exchange in the Pomeron term, these distributions are rather well described. The distribution in $t_{K^- \bar{K}^0}$ for $K^-p \rightarrow \bar{K}^0 \pi^- p$ (Fig. 6a) shows much less peaking than that in $t_{K^-K^-}$, as can be expected of a reaction to which the Pomeron does not contribute.

In Fig. 5 the experimental and predicted mass distributions for the K^+p class (I) and (II) reactions at 3.5 GeV/c are shown normalized to the experimental and predicted reaction cross-sections, respectively. For $K^+p \rightarrow K^+ \pi^0 p$ and $K^+p \rightarrow K^0 \pi^+ p$ the measured values are 1.32 ± 0.07 and 1.87 ± 0.09 mb and the predicted ones, 0.80 and 1.55 mb, respectively. All curves are absolute predictions with the 10 GeV/c K^-p data as a starting point. For class (I) the main resonances are roughly correctly described, as those we used to establish the connection between classes (I) and (II), and the disagreement lies mainly in the background.

We do not present any distributions in the decay angles of the resonances, since there are hardly any data available. The dual term predictions are similar to those in Ref. 1). The angular distribution in the decay angles in the resonance rest frame predicted by the dual term is for the first pole (e.g., the K^* or the Δ) of the form $w(\cos\theta, \varphi) = \sin^2\theta \sin^2\varphi$, which arises entirely from the kinematical factor. For the K^* this corresponds to the constant values $\rho_{11} = \rho_{1,-1} = \frac{1}{2}$, and for the Δ to $\rho_{33} = \frac{1}{2}$, $\text{Re } \rho_{3,-1} = \sqrt{3}/4$ (to be compared with the Stodolsky-Sakurai values $3/8$ and $\sqrt{3}/8$, respectively), all the other density matrix elements vanishing. The background from the amplitudes which do not have these poles distorts this distribution slightly. A disagreement in the angular distribution of the Δ is to be expected, since its spin is not treated correctly. At the second pole (e.g., the K^{**}) the density matrix elements will depend on the momentum transfer. The Pomeron term predicts sharply peaked distributions in the Jackson angles and a constant distribution in the Treiman-Yang angle in the $\pi^0 p$ rest frame.

Summarizing, we have come to the following conclusions.

- a) In the reactions $K^\pm p \rightarrow K^\pm \pi^0 p$ there is a large ($\approx 50\%$ of the total at 10 GeV/c) contribution from Pomeron exchange. The magnitudes of this exchange obtained from factorization and by fitting distributions agree roughly. However, at present the Pomeron contribution cannot be separated from small dual correction terms to the main dual vector exchange term. The relative importance of the Pomeron contribution increases rapidly with energy.

- b) The vector exchange contributions to classes (I), (II) and (III) can be connected by isospin by choosing a fixed set of reactions (above the reactions with K^+p initial state) and determining the coefficients of the dual amplitudes so that the first prominent resonances are produced with correct isospin branching ratios. When crossed to other channels, the amplitude so obtained may violate isospin. Thus isospin gives additional constraints leading in some cases to disagreement with experiment.
- c) In the present simple form with minimum number of dual terms, the model can be applied only at high energies ($p_L \gtrsim 3 \text{ GeV}/c$) and to a limited set of reactions at a time. An extension to all energies and all channels, if at all possible within the framework of dual resonance models, will require a correct treatment of both spin and isospin and the inclusion of a larger number of dual amplitudes.
- d) For class (III) reactions, the present work gives both the amount of Pomeron exchange [twice the amount in class (I)] and the amount of dual vector exchange [Eq. (3.3) and Fig. 3].

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FIGURE CAPTIONS

Figure 1 : Pomeron exchange diagram for the reactions $K^\pm p \rightarrow K^\pm \pi N$.

Figure 2 : The three relevant graphs for the construction of the dual part of the amplitude for the reactions $K^- p \rightarrow K^- \pi^0 p$. The trajectory coupling to the channel is denoted between the adjacent lines. The graphs for the $K^+ p$ reactions are obtained by crossing from the channel in which p_a and p_b are incoming to the channel in which p_a and p_3 are incoming.

Figure 3 : The total cross-sections as functions of p_{lab} .

- (a) Reaction $K^- p \rightarrow K^- \pi^0 p$ [Ref. 9]. The solid curve σ^I is the prediction for this reaction according to (4.1). The solid curve σ_V^{III} is the prediction for the vector dual part of the amplitude $[A_V^{III}]$ of (3.3) for the reaction $K^- p \rightarrow K^- \pi^+ n$. The dashed curve is the prediction for the Pomeron contribution according to (2.1). The structure seen at low energies is due to the s channel resonances $\Lambda(1815)$, $\Lambda(2100)$ and $\Lambda(2350)$.
- (b) Reactions $K^+ p \rightarrow K^+ \pi^0 p$ and $K^+ p \rightarrow K^0 \pi^+ p$ [Ref. 8]. The solid curve σ^I is the prediction for $K^+ p \rightarrow K^+ \pi^0 p$ according to (4.1). The solid curve σ^{II} is the prediction for $K^+ p \rightarrow K^0 \pi^+ p$ according to A_V^{II} of (3.3). The solid curve σ_V^{III} is the prediction for the vector dual part of the amplitude according to A_V^{III} of (3.3) for the reaction $K^+ p \rightarrow K^+ \pi^+ n$. The dashed line is the prediction for the Pomeron contribution according to (2.1).

Figure 4 : Reaction $K^- p \rightarrow K^- \pi^0 p$. Effective mass distributions in percentages at 2.7 GeV/c (1513 events), 4.57 GeV/c (401 events) and 10 GeV/c (1009 events). The solid curves are the predictions for the sum of the dual and the Pomeron contributions, while the dashed curves represent the Pomeron contributions only.

- Figure 5 : (a) Reaction $K^+p \rightarrow K^+ \pi^0 p$ (839 events).
(b) Reaction $K^+p \rightarrow K^0 \pi^+ p$ (1696 events).

Effective mass distributions in percentages at 3.5 GeV/c.
The solid curves are the predictions for the sum of the dual and the Pomeron contributions normalized to the corresponding predicted cross-sections (see Fig.3).

- Figure 6 : The momentum transfer distributions

- (a) $t_{K^-K^-}$ and
(b) t_{pp} .

In percentages for the reaction $K^-p \rightarrow K^- \pi^0 p$ at 10 GeV/c.
The solid curves are the predictions for the sum of the dual and the Pomeron contributions. The dashed curves represent the Pomeron contribution only. The dotted histogram in (a) is the distribution in $t_{K^-K^0}$ for $K^-p \rightarrow \bar{K}^0 \pi^- p$.

FIG. 1

FIG. 2

FIG. 3

FIG.4

a)

b)

FIG.5

FIG.6