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Status of the Regge-pole model for KN scattering

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We compare the data on $K^{\pm}p$ elastic, KN charge-exchange, and $\pi^- p \to \eta^0 n$ scattering with several classes of models. We show that the simple Regge-pole model is surprisingly good except for certain discrepancies with the data in and near the forward direction. It is found that if we add high-energy terms of a quadratic form in $\log s$ to all exchanges while at the same time imposing certain desirable restrictions (for example exchange degeneracy) on the Regge-pole parameters, an accurate description of the data can be obtained. Polarization predictions at high energy clearly distinguish between the different types of model and KN charge-exchange and η^0 production are shown to offer the best test of the existence of these unconventional effects near $t = 0$.

I. INTRODUCTION

Recently, a large number of new and accurate data on kaon-nucleon[1] and on $\pi^- p \to \eta^0 n$ scattering[2] have been obtained at Fermilab. The data on these processes now cover a large energy range and their energy dependence can now be tested in a much more significant way than has been possible in the past. This is especially important in the light of the interesting features already observed in pion-nucleon scattering. Namely that in pion-nucleon charge exchange[3] the simple Regge-pole model can describe the data very well, except near the forward direction, where either new, unconventional high-energy terms,[4] or an unusual ρ trajectory[3] must be introduced.

The existence of unconventional contributions localized at small $|t|$ has recently been predicted in the theoretical framework of the topological expansion.[5] However, since the rules for the phenomenological application of this approach are not yet completely established we will adopt in the present paper a more pragmatic point of view. We will compare the data on kaon-nucleon scattering and η^0 production with several classes of models which are a natural extension of the models used in Ref. 4 to the more complicated KN system.

We arrange this paper as follows. In Sec. II we describe the various models starting with the simplest Regge-pole model and going on to more complicated ones. In Sec. III we analyze the data in the framework of these models. Section IV is devoted to predictions, especially for the polarizations at high energy. We present our conclusions in Sec. V.

II. MODELS

In this section we describe the various models which we will test against the KN and $\pi^- p \to \eta^0 n$ data. We use A' and B, which are the usual invariant amplitudes[6] in the same normalization as used for $\pi^- p \to \pi^0 n$ in Ref. 4 (with the appropriate isospin factors for the various KN processes). The data which we fit contain all the high-energy data on polarization and differential cross sections for $K^{\pm}p$ elastic, $K^{\pm}N$ charge-exchange, and $\pi^- p \to \eta^0 n$ scattering as well as the $K^{\pm}p$, $K^{\pm}n$ total-cross-section measurements. Since we wish to exclude lower-lying Regge trajectories we choose our lower cutoff at $p_{\text{lab}} = 5$ GeV/c. This enables us to ignore the possibility of A'_2 and ρ' complications found at lower energies,[7,8] although these terms may possibly still be of importance at higher energy, especially in the polarization. We also include in our data set the πN data at $t = 0$ as constraints on the ρ trajectory. This includes the total-cross-section difference $\Delta\sigma(\pi N) = \sigma(\pi^- p) - \sigma(\pi^+ p)$ and $d\sigma/dt\,(\pi^- p \to \pi^0 n)$ at $t = 0$. This is motivated by the possible discovery of unconventional effects in this process[4] which manifested themselves especially at $t = 0$. We have a total number of about 1400 data points. See Ref. 9 for a bibliography of the data.

A. Regge-pole models

In these models we express the scattering amplitude in terms of the five t-channel exchanges P, f, ω, ρ, and A_2 with the appropriate isospin and SU(3) factors connecting their contributions to the various processes.[10] We will call this model the five-pole model (5PM). The P, f, ω, ρ, and A_2 are all treated as pure Regge poles. With the exception of the ω and ρ non flip amplitudes the Regge-pole forms chosen are the simplest compatible with the removal of unphysical wrong-signature poles in the range of t under study, with the ρ, ω choosing nonsense and the A_2, f choosing sense.

We thus write the amplitudes in the form

$$\begin{aligned} A'_+ &= a_+\alpha_+(t)\xi_+(t)(s/s_+)^{\alpha_+(t)} \ , \\ B_+ &= b_+\alpha_+(t)\xi_+(t)(s/s_+)^{\alpha_+(t)-1} \ , \\ A'_- &= a_-(t)(a_-(t)(\alpha_-(t)+1)\xi_-(t)(s/s_-)^{\alpha_-(t)} \ , \\ B_- &= b_-\alpha_-(t)(\alpha_-(t)+1)\,\xi_-(t)(s/s_-)^{\alpha_-(t)-1} \ , \\ \xi_+(t) &= i - \cot(\pi/2)\alpha_+(t), \\ \xi_-(t) &= i + \tan(\pi/2)\alpha_-(t) \ . \end{aligned} \tag{1}$$

The ω, ρ nonflip amplitudes in KN scattering are known to contain structure not directly attributable to the simplest Regge-pole model (i.e., with constant residues). It is clear from the amplitude reconstruction of Ref. 11 and from elastic-differential-cross-section measurements that $a_-(t)$ has at least one zero at $t=-0.2$ and possibly another at larger t. We used in our fits both a single zero function $a_-(t)=a(1+ct)$, which is certainly adequate for $|t|<1.0$ and also $a_-(t)=J_0(R\sqrt{-t})$. A comparison of the two fits will be made below.

These Regge models have a large number of parameters (27), but many of them are quite well determined and the large number of data points makes a search on the others completely meaningful.

B. Non-Regge and hyper-Regge models

1. Non-Regge terms in vacuum-exchange contributions only

In subsection (A) we considered a pure pole model in which all five poles P, f, ρ, ω, and A_2 behaved as simple Regge poles. It is also possible that the rising component is given by a more complicated singularity than the simple pole situated at $J=1$. One example of this is the "logarithm-squared-Pomeron" (LSP), whose s dependence at $t=0$ is the maximum permitted by the Froissart bound. That is, a term of the form

$$is\,[a(\ln^2 s - i\pi\ln s)+b(\ln s - i\pi/2)]\,\lambda(\tau) \tag{2}$$

is added to the A' amplitude. We do not include a similar term in the B amplitude for the following reason. At t close to zero where the rising component must (by unitarity) be observed, the B amplitude has a negligible contribution and the addition of a term such as Eq. (2) to B would have little effect except on the polarization at large $|t|$. We should also note that since the energy dependence of Eq. (2) is the maximum permitted by the Froissart bound the t dependence is constrained by axiomatic field theory,[12] to be a function of $\tau=-t\ln^2 s$ only; however, we use a simple exponential. Our analysis could not distinguish between the two cases.[19]

The other Regge poles f, ρ, ω, A_2 have exactly the same form as in subsection A.

2. Non-Regge and hyper-Regge terms in the non-vacuum-exchange contributions

In Ref. 4 we found that, in order to describe the data on $\sigma(\pi^-p)-\sigma(\pi^+p)$ and $d\sigma/dt\,(\pi^-p\to\pi^0 n)$ in every detail, it was necessary to include a singularity at $J=1$ in the t-channel amplitude with ρ quantum numbers. This observation depends critically on the phase of the amplitude at $t=0$. For kaon-nucleon and η production, the data are not so accurate and such effects would be less easy to detect. Any attempt to include both non-Regge or hyper-Regge terms and four independent Regge poles would lead to a proliferation of parameters and gain us no real knowledge of such effects and their contribution to the KN and η production processes.

We thus propose that we start with a model in which the Regge poles satisfy EXD and universality and that the apparent breaking of the EXD and/or universality of the Regge-pole parameters is caused at least in part by these unconventional contributions. We thus look at the following models in which the Regge poles are constrained to satisfy the following conditions. Either

(A) all four Regge poles satisfy EXD and obey SU(3) and universality (by EXD we mean having degenerate trajectories and coupling constants equal at $t=0$), and all the apparent breaking of the above constraints arises from these singularities at $J=1$, or

(B) we permit EXD to be broken by either the pairs of Regge poles

(1) $3\rho=\omega$ and $3A_2=f$ or

(2) $\omega=f$ and $\rho=A_2$.

The breaking of EXD between the pairs arises from the Regge-pole parameters but the observed breaking of the equalities for the total contributions to the amplitude is now caused by the unconventional terms.

We have, therefore, a model in which desirable properties of the Regge poles are retained, whereas all deviation from these properties at high energies is explained by non-Regge (or hyper-Regge) terms. We are thus testing something different from that in Ref. 4, where non-

Regge effects were implied by the data. We are finding out what high-energy terms are needed to give the observed behavior of the various quantum-number-exchange channels and what effect these will have on high-energy predictions, in a series of constrained models.

(i) Hyper-Regge models. In Ref. 4 we considered two models with $J=1$ singularities. In the so-called hyper-Regge models we introduced a simple pole at $J=1$ into the relevant amplitude. This arises in a natural way from considering dispersion relations for the antisymmetric amplitude. In general the real part includes a real subtraction constant which corresponds to a simple pole at $J=1$. The coefficient of this term is only zero, as it is generally assumed to be, if the amplitude has Regge behavior not only on the real axis in the s-u plane, but around the contour at infinity. Since this cannot directly be tested, such a term can in principle be present and has been used to explain certain features in πN and NN data.[4,13] Since this is similar to the Pomeron, but contributes to the odd-signature amplitude, we shall refer to it as the "odd Pomeron."

We thus introduce such a singularity in the ρ, ω quantum-number-exchange channels. In the A_2, f components the analogous term is like the Pomeron. (Its contribution to the f-like amplitude can of course be absorbed into the usual Pomeron.) At $t=0$ our model thus adds a purely imaginary one to the A_2 amplitudes in addition to the Pomeron and the Regge poles constrained according to either (A), (B1), or (B2). We take the SU(3) couplings when relating the KN, A_2 amplitudes to that for $\pi^-p\to\eta^0 n$.

(ii) Non-Regge models. The original suggestion that the rise in total cross sections seen at Fermilab and CERN ISR may be only one manifestation of the principle of "maximal behavior" of amplitudes at high energy[14] leads to the result that all A' amplitudes contain a term (which we will call Q) such as

$$A'_Q(s,t=0)=s[\delta\ln^2 s-i\pi\ln s)+\gamma(\ln s-i\pi/2)+\beta]\,i^{\epsilon}, \tag{3}$$

where

$\epsilon=0$ (1) if A' is odd (even)—under crossing.

The effect of a term such as this has already been studied in $\pi^-p\to\pi^0 n$ (Ref. 4). In this section we intend to study what happens if we include a Q contribution in KN scattering amplitudes. We choose to add a Q-like term to the ρ, A_2 and ω exchange amplitudes but only in A'. This choice is motivated partly because the nonflip amplitude is more important near $t=0$ where unconventional effects are best detected, partly, because it is the A' amplitude that shows most deviation from standard Regge-pole models, and also because adding such a term to B would serve more to increase the number of parameters to be fitted than to increase our knowledge of the Q contributions.

As in the odd-Pomeron case above we will only consider models in which the Regge poles themselves satisfy additional constraints, i.e., (A), (B1), and (B2) as described above. For example, this leads to a prescription for KN charge-exchange scattering where all deviations from the Regge-pole model, and in two of the above cases, all deviations from exchange degeneracy, are concentrated in the nonflip amplitudes, as, for example, the analyses of Refs. 15 would suggest.

Again, as far as the t dependence of the Q term is concerned, we set $A'(s,t)=A'(s,0)e^{\lambda t}$, where λ is constant, which is a reasonable phenomenological parametrization for the energy range in which we are interested. In the absence of any structure in the t dependence the large t behavior of this term is clearly not reliable, but this work is not the place for a detailed examination of such effects.

The number of parameters in these non-Regge models is comparable with those in the Regge models.

III. ANALYSIS OF THE DATA

We split the data into two parts: $t\neq 0$ and $t=0$. For $t\neq 0$ we have the differential cross section and polarization data on $K^\pm p$ elastic, $K^\pm N$ charge exchange, and $\pi^-p\to\eta^0 n$. At $t=0$ we include total cross sections for $K^\pm p$, $K^\pm n$, and the difference $\Delta\sigma(\pi N)$ as well as the extrapolations of $d\sigma/dt$ ($K^\pm N$ CEX), $\pi^-p\to\eta^0 n$, and $\pi^-p\to\pi^0 n$ to $t=0$. We check in each case first of all whether the model can describe the $t=0$ data, and then if this is successful we then fit all the data simultaneously. We shall see that $t=0$ data alone rule out many of the alternatives. In all, we have 1355 data points.

A. Regge models and models with non-Regge terms for the Pomeron only

These models, both the 5PM and the LSP, were quite successful in fitting the data [($\chi^2(t=0)$ of 1.14–1.25/point and $\chi^2(t\neq 0)$ of 1.74–1.93/point]. The principal problems were that the crossing-odd component $\sigma(K^-p)-\sigma(K^+p)$ shows some discrepancy from the Regge-pole model at high energy (Fig. 6) and there is a slight difficulty for small $|t|$ in $d\sigma/dt$ ($K^\pm p$ elastic).

As far as the distinctive differences between the two are concerned, we found that the crossing-even component $\sigma(K^-p)+\sigma(K^+p)$ was better fitted by the LSP rather than the 5PM, though this differ-

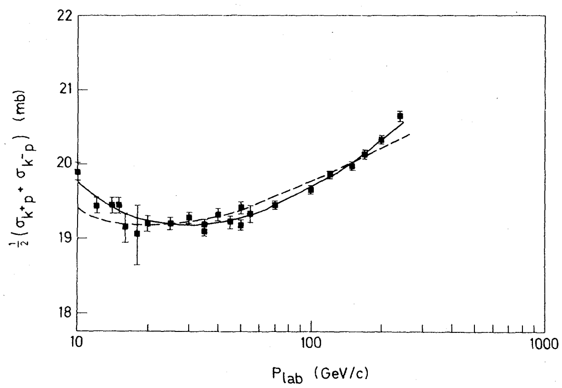


FIG. 1. $[\sigma(K^+p)+\sigma(K^-p)]/2$ data compared to the LSP model (solid line) and the Pomeron-f identity model (dashed line).

ence is not very great. In Fig. 1 we show the better fit of the two. We also found that in the 5PM the differential cross sections for $K^\pm p \to K^\pm p$ are built out of the A' amplitude right out to large $|t|$, whereas in the LSP model the B amplitude becomes important for $|t| > 0.65$. The shape of the polarization in K^-p is little affected by this, although $P(K^\pm p)$ is changed somewhat at large $|t|$ [Figs. 2(a) and 2(b)].

In comparing with models which have a Bessel function for the ρ, ω nonflip residue the most distinctive difference is the failure of the models without a second zero to give the correct shape at large $|t|$ both for $P(K^\pm p)$ (shown in Fig. 2) and for $d\sigma/dt\,(K^\pm p)$. The behavior of the polarization is quite well described using a Bessel-function residue, but the structure at $|t| \approx 1.2$ in $d\sigma/dt$ is likely to originate from a more complicated form of the Pomeron form factor,[17] as this cannot wholly be explained by the ω exchange component. We thus concentrate on $|t| < 1.0$, where the Pomeron may be reasonably expected to show a simpler t dependence.

If one also considers $P(K^-p \to \bar{K}^0 n)$, there arises a problem whichever form of the $\omega(\rho)$ nonflip amplitude one chooses. If one uses $J_0(R\sqrt{-t})$ one finds that there is a zero in the charge-exchange polarization at $\alpha_\rho(t)/\alpha_0 \simeq J_0(R\sqrt{-t})$ which is not present in the data at 8 GeV/c. Thus although the elastic data prefer J_0, the charge-exchange data prefer the single zero residue. The discrepancy between

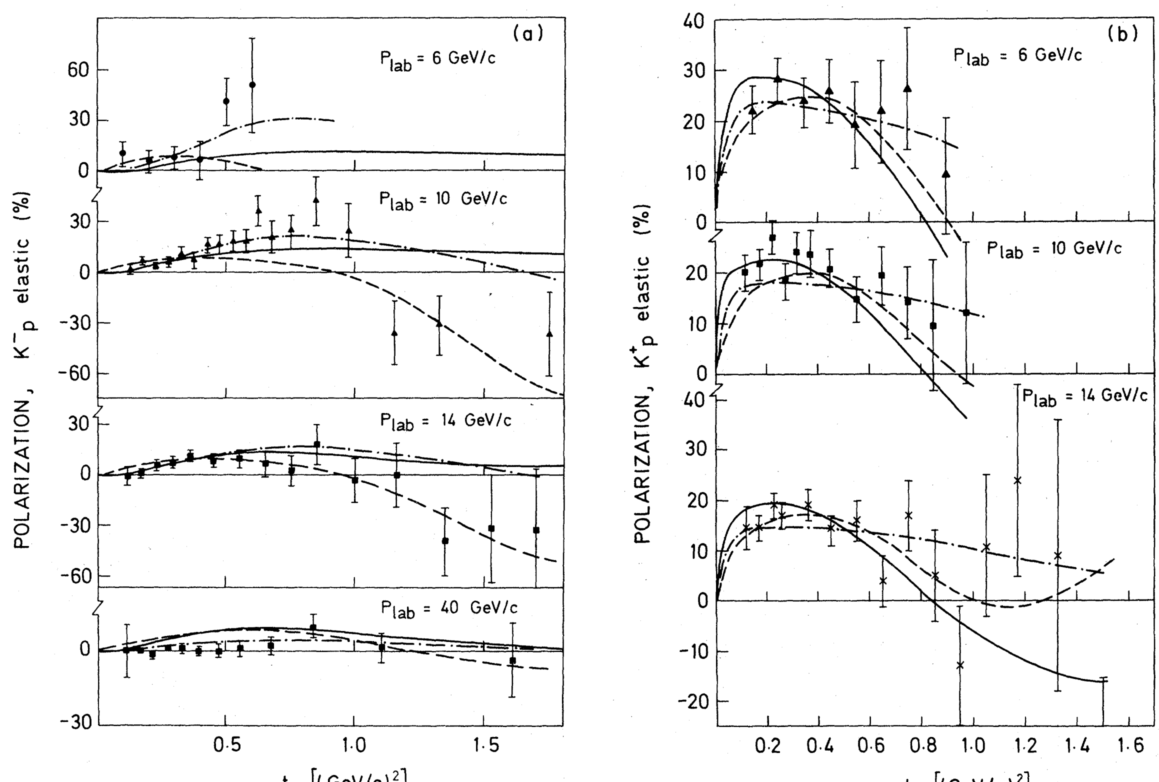


FIG. 2.(a) K^-p elastic polarization data compared to (i) LSP with linear zero residue (solid line), (ii) LSP with Bessel function residue (dashed line), and (iii) 5PM with linear zero residue (dash-dotted line). (b) As for (a), but for K^+p elastic polarization data.

the two may be explicable in terms of ρ' and A_2' (see Ref. 7) exchanges which are perhaps still important in $P(K^-p \to \bar{K}^0 n)$ at this energy but insignificant in the elastic polarization (Fig. 3).

The numerical values of R in the $J_0(R\sqrt{-t})$ residues of A_ρ' and A_ω' correspond to $R = 0.84$ fm and $R = 1.12$ fm, respectively, which agrees with the usual statement that these exchanges are peripheral.

As far as the other parameters of the various fits are concerned, these are given in Table I, where we have defined

$$A_R'(s, t=0) = C_a^R s^{\alpha_0}$$
$$B_R(s, t=0) = C_b^R s^{\alpha_0 - 1} (C_{a,b} \text{ in mb GeV}) . \quad (4)$$

The values for the parameters quoted in Table I are the mean values averaged over the various fits. The "errors" quoted denote difference (if any) between the best-fit parameter values.

The ρ and A_2 contributions are well determined and the $t=0$ couplings of both B, A' amplitudes are very similar, virtually all the EXD breaking coming from the difference in trajectory. The ω nonflip contribution is well determined and $C_a^\omega > 3C_a^\rho$ (where $C_a^\omega = 3C_a^\rho$ comes from ω universality).

Away from $t=0$ we can see that the difference in the ρ and A_2 trajectories is quite adequate to describe $P(K^-p \to \bar{K}^0 n)$ (Fig. 3) and both $d\sigma/dt\,(K^-p \to \bar{K}^0 n)$ and $(\bar{K}^+ n \to K^0 p)$, except possibly at higher energies and at small t where the Serpukhov data present a slight problem (Fig. 4).

The f, as one would expect, is quite badly determined, and its almost consistency with zero raises the possibility that it may be possible to fit the data with only one important vacuum exchange trajectory as in the f dominance of the Pomeron models. Since we include total-cross-section data on $K^\pm n$, $K^\pm p$, and $\pi^\pm p$ and extrapolations of $d\sigma/dt\,(t=0)$ of $K^\pm N$ CEX and $\pi^- p \to \pi^0(\eta^0) n$ over the range $p_2 = 5$ to 240 GeV/c our constraints are quite strong. Even allowing ρ-A_2 EXD to be broken, a good fit is not possible mainly because of a poor description of the crossing-even channel $\sigma(K^-p) + \sigma(K^+p)$ (where $\chi^2 > 4$/point), which is shown in Fig. 1. It is clear from this that some additional term is necessary as is found in Ref. 16. This could either be the orthodox f exchange or higher-order corrections to the f-dominated Pomeron from any of various different mechanisms.[5]

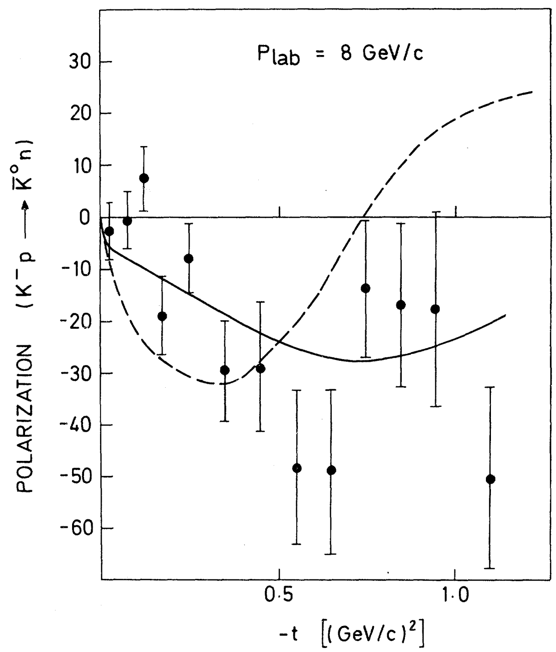


FIG. 3. $K^-p \to \bar{K}^0 n$ polarization data compared to LSP with linear zero residue (solid line), and LSP with Bessel function residue (dashed line).

The parameters for the Pomeron are

$$\text{5PM:} \quad C_a^P = 14.3 \quad C_b^P = -1.9 \quad \alpha_0 = 1.064, \quad \alpha' = 0.145, \quad (5a)$$

$$\text{LSP:} \quad C_a^P = 19.9, \quad C_b^P = 37.0, \quad \alpha' = 0.22,$$
$$a = 0.178, \quad b = -0.72 \quad \text{[see Eq. (2)]}. \quad (5b)$$

The smallness of C_b^P in the 5PM is remarkable since the pure-pole Pomeron thus couples *over-*

TABLE I. Parameters of fits [see Eq. (4)]. The values given are mean values averaged over the various fits. The "errors" quoted denote difference (if any) between the best-fit parameter values.

	ρ	ω	A_2	f
C_a (mb/GeV)	2.39 ± 0.01	10.2 ± 0.3	2.25 ± 0.01	3.56 ± 2.63
C_b (mb/GeV)	42.5 ± 1.9	13.0 ± 13.0	36.8 ± 0.9	8.93 ± 7.56
α_0	0.49	0.47 ± 0.01	0.37	0.44 ± 0.13
α' [(GeV/c)$^{-2}$]	0.82 ± 0.07	1.06 ± 0.20	0.70 ± 0.01	0.36 ± 0.17

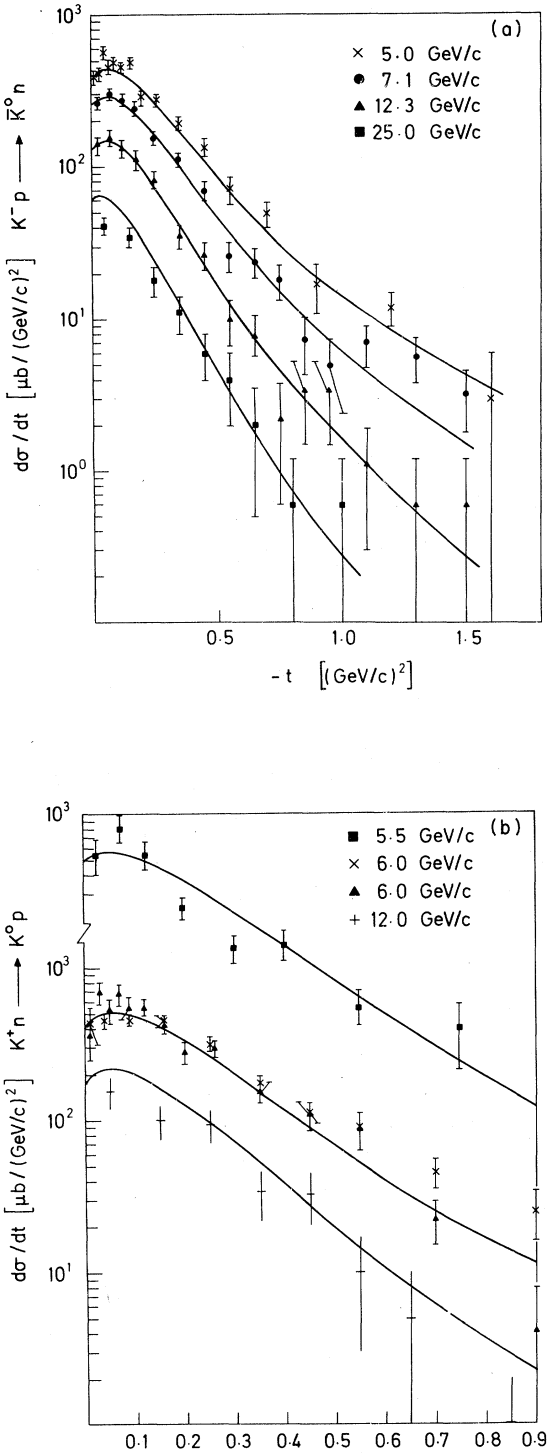


FIG. 4. (a) $K^-p \to \bar{K}^0n$ differential cross section and LSP model with linear zero residue. (b) $K^+n \to K^0p$ differential cross section as in (a).

whelmingly to the t-channel no-flip amplitude. The intercept $\alpha_0 = 1.064$ is comparable to those for the πN and NN systems (e.g., Ref. 17).

B. Non-Regge and hyper-Regge models

(i) Odd-Pomeron models. The first test of these models is whether they can fit the $t=0$ data alone. We intend, as mentioned in Sec. II, to only consider models in which the Regge poles are constrained:

$$\text{(A)}\quad 3C^{\rho}_{a(b)} = 3C^{A_2}_{a(b)} = C^{\omega}_{a(b)} = C^{f}_{a(b)},$$

$$\alpha_\rho = \alpha_{A_2} = \alpha_f = \alpha_\omega,$$

$$\text{(B1)}\quad 3C^{\rho}_{a(b)} = C^{\omega}_{a(b)},\quad 3C^{A_2}_{a(b)} = C^{f}_{a(b)},$$

$$\alpha_\rho = \alpha_\omega,\quad \alpha_{A_2} = \alpha_f,$$

$$\text{(B2)}\quad C^{\rho}_{a(b)} = C^{A_2}_{a(b)},\quad C^{\omega}_{a(b)} = C^{f}_{a(b)},$$

$$\alpha_\rho = \alpha_{A_2},\quad \alpha_\omega = \alpha_f.$$

As far as the class of hyper-Regge models is concerned, we can see that (A) and (B1) can be ruled out by the total-cross-section data on $\sigma(\pi^-p) - \sigma(\pi^+p)$ and $\sigma(K^-p) - \sigma(K^+p)$. These are proportional to the imaginary part of the ρ and $\rho+\omega$ nonflip amplitudes, respectively, and since the odd-Pomeron contributions to these amplitudes at $t=0$ are purely real these quantities are fitted in effect by only simple poles. We know from Sec. III A that the equality $C^\omega_a = 3C^\rho_a$ is violated and the attempt to fit the data with this constraint is poor ($\chi^2 = 3$/point for the two data sets).

For case (B2) the problem is to describe the observed EXD breaking between the ρ- and A_2-quantum-number-exchange contributions. The Regge pole ρ and hence A_2 is in effect fixed from $\Delta\sigma(\pi N)$ and hence the difference in behavior of $d\sigma/dt\,(\pi^-p \to \eta^0 n)$ and $d\sigma/dt(\pi^-p\to\pi^0 n)$ has to be described by the $J=1$ singularity contributions to the relevant amplitudes. This turns out not to be possible as can be seen from Fig. 5. The strong energy dependence of the ratio $R = d\sigma/dt\,(\pi^-p\to\pi^0n)/d\sigma/dt\,(\pi^-p\to\eta^0 n)$ at $t=0$ cannot be reproduced in this model.

We thus conclude that it is not possible to include any of the desired constraints on the Regge poles in a model that has only simple poles at $J=1$ in the non-vacuum-quantum-number-exchange channels. We therefore turn our attention to the non-Regge models.

(ii) Non-Regge models. We adopt the same philosophy here as in (*i*) above. We test to see if we can make constraints on the Regge-pole-model couplings and intercepts and include the Q contribution in ρ-, ω-, A_2-quantum-number-exchange amplitudes first at $t=0$. We do, in this case, have a larger number of parameters at our

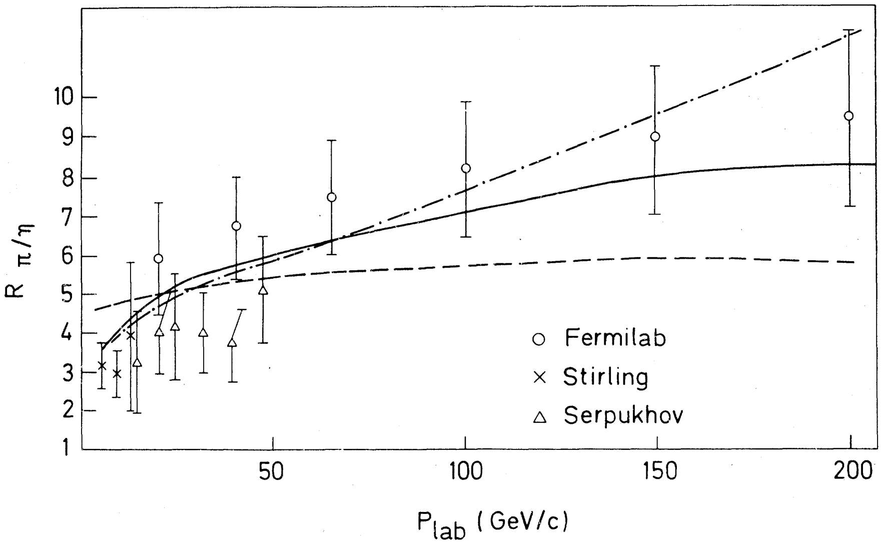


FIG. 5. The ratio $R_{\pi/\eta} = [d\sigma/dt(\pi^- p \to \pi^0 n)]/[d\sigma/dt(\pi^- p \to \eta^0 n)]$ at $t = 0$ compared to LSP model (solid curve), hyper-Regge model (dashed curve), and non-Regge model (B2) (dash-dotted curve). For further details see text.

disposal [13 and 15 for cases (A) and (B), respectively instead of 7 and 9 in the hyper-Regge model], but it is nonetheless of some significance that excellent fits to the $t = 0$ data can be achieved in all three cases, and that the fits are better than those obtained in the orthodox Regge-pole model.

The improvement in the description of the πN system has already been studied, so here we show the respective fits for $\sigma(K^- p) - \sigma(K^+ p)$, Fig. 6. We can see in Fig. 6 a qualitative change at high energy, where the Q-model fit is much better than the Regge-pole model.

The ratio R can also be seen in Fig. 5 for the various models. The Q-model fit shown is that for model (A) with complete EXD and universality. We can see that the observed difference between the ρ-, A_2-quantum-number-exchange channels is easily explained in terms of a non-Regge contribution to these amplitudes; the data are well described. Other quantities at $t = 0$ show only statistical rather than systematic improvements over the Regge-pole model.

It is thus meaningful to include the $t \neq 0$ data in a global fit. Since we have used a rather crude cutoff for the non-Regge term ($e^{\gamma t}$) we might expect our fits to the large-$|t|$ date to be somewhat unreliable, and we concentrate on the comparison with experiment for smaller $|t|$ values [i.e., $|t| < 1.0 (\mathrm{GeV}/c)^2$]. For the three different cases above the overall χ^2's for 1355 data points are 1.92, 1.76, 1.54/point, so taken over the whole set of data the last of the three is *comparable* with those models that do not include unconventional terms in the Regge-exchange amplitudes. The first two are slightly worse.

We now concentrate on the individual processes. First we consider the elastic ones. These are dominated by the Pomeron as in the pure-Regge-pole model, but now our secondary terms differ in that they are constrained by condition (A), (B1), or (B2), and this reduction of freedom is compen-

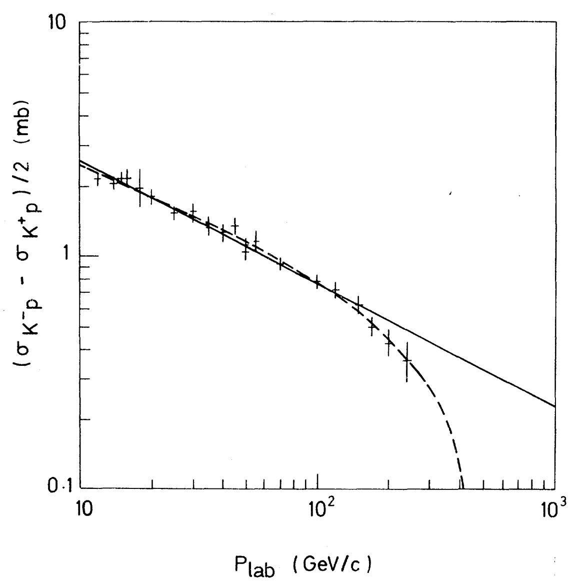


FIG. 6. $[\sigma(K^- p) - \sigma(K^+ p)]/2$ data compared to LSP model (solid line), and non-Regge model (B2) (dashed line).

sated by the possibility of the unconventional contributions in these amplitudes. The fits are good and for $|t| < 1.0$ $(\mathrm{GeV}/c)^2$ the differential cross-section data are well described from $P_{\mathrm{lab}} = 5$ to 200 GeV/c in all three cases above; both the shape and the position of the crossover at small $|t|$ are given just as well in this model as in the pure Regge-pole model (or LSP model). Thus the non-Regge contribution which gives the curvature in $\sigma(K^-p) - \sigma(K^+p)$ at high energy (Fig. 6) is completely compatible with the data in this range of $|t|$ (Fig. 7).

The polarization is a more sensitive test of the phase of the amplitudes, which the non-Regge terms, since they are singularities at $J = 1$, radically alter. Thus we can distinguish among the three models in this section more easily by the polarization. In models (A) and (B1) when $3C_a^\rho = C_a^\omega$ and $3C_a^{A_2} = C_a^f$, it is impossible to fit the shape of $P(K^\pm p)$ at all. This is clearly caused by the too great magnitudes of the ρ, ω contributions to the B amplitude, which, although badly determined, cannot be as large as is required by universality (see Table I). This fact manifests itself most clearly in this failure to fit the $K^\pm p$ polarizations. We should stress that it is not at all obvious that this should be so since the effect of non-Regge terms in the A' amplitude will change the arguments usually used to infer this result. What in fact happens is that the large $B_{\omega,f}$ contributions lead to a large Regge-Regge term in the polarization with a zero at smallish t which is not seen in the data (see Fig. 8).

On the other hand, if we consider case (B2) in which $\rho = A_2$ and $\omega = f$ but universality is not imposed, then an excellent fit to the K^+p polarization is achieved (Fig. 8). Now the B coupling of the ω and f is between 10 and 25, whereas 98.7 would be required by exact universality. We thus conclude that models (A) and (B1) are unsatisfactory.

As far as the K^-p polarization is concerned in this model, the difference between the J_0 and

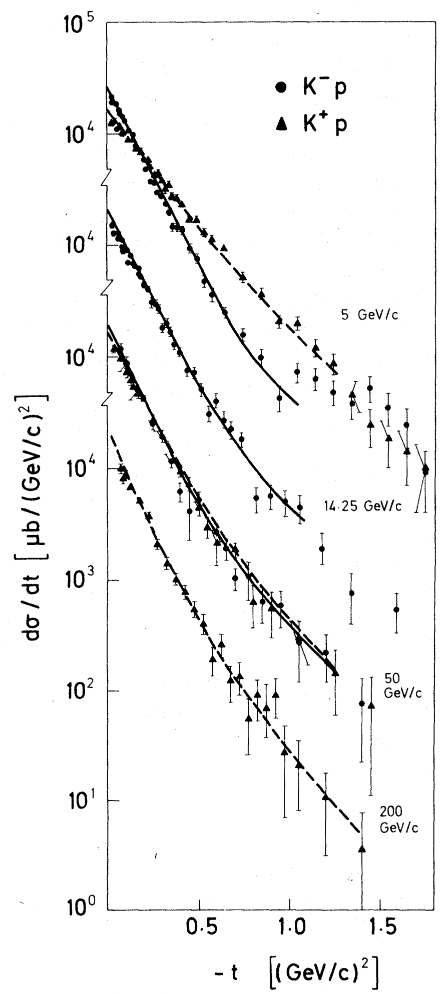


FIG. 7. K^-p and K^+p elastic differential cross section plotted against the non-Regge model (B2) for $|t| \lesssim 1.0$ $(\mathrm{GeV}/c)^2$.

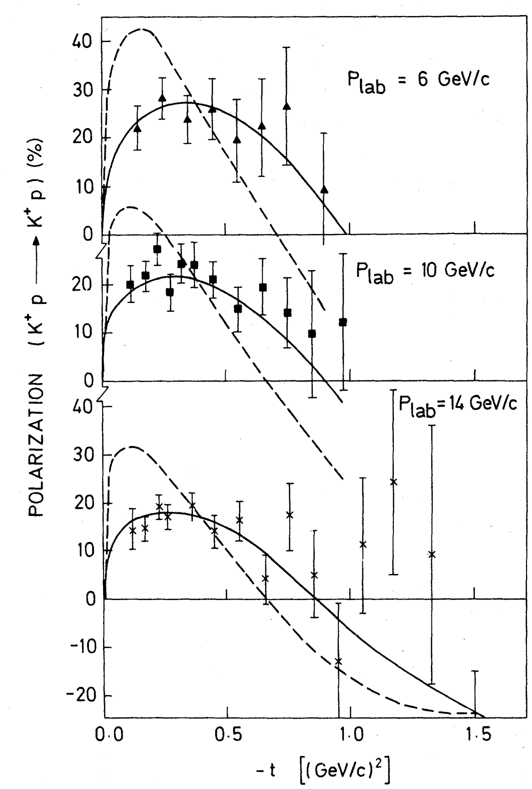


FIG. 8. K^+p elastic polarization data compared to the non-Regge models (B1) (dashed curve) and (B2) (solid curve).

linear zero for the ω, ρ nonflip residues is again important (this difference appears to have little effect on the K^+p polarization). Again we get a very poor fit to the data using the linear zero; the fit is of opposite sign to the data for $|t| \geq 0.5\,(\mathrm{GeV}/c)^2$. However, using the J_0 gives a shape close to that of the Regge-pole model with the same type residue, as shown in Fig. 3.

In the KN charge-exchange process our only EXD-breaking term is in the A' amplitude. We find that it is not possible to fit the data. This would be suggested by those analyses that claim some EXD breaking is necessary in the B amplitude too.[7] If one were to permit EXD breaking [i.e., model (B)] the difference $d\sigma/dt\,(K^-p \to \bar{K}^0n) - d\sigma/dt\,(K^+n \to \bar{K}^0p)$ could be better described, but we have already seen that this model is unsatisfactory from the $K^\pm p$ elastic data.

Thus we must conclude that unless we are prepared to free all the Regge-pole parameters such a model cannot describe the data. There are also several other possibilities. The sensitivity of these two processes to possible lower-order effects, i.e., ρ', A_2' (Ref. 7) makes it difficult to make definitive claims, and it is certainly necessary to include a ρ' in the $\pi^-p \to \pi^0n$ reaction.

Since our aim is largely to compare the Regge-pole model with models which include non-Regge effects to see what evidence of non-Regge effects may be seen at higher energies, we can conclude that KN CEX is not a good place to look at these energies. It probably relates as well to the facts that the phase in these processes is badly determined at $t=0$ and that the B amplitude is dominant. It thus needs exceedingly good data away from $t=0$ (as for example in $\pi^-p \to \pi^0n$) to fix the phase of B and good data for $t=0$ to fit the phase of $A'(t=0)$. In KN CEX this information is just not present.

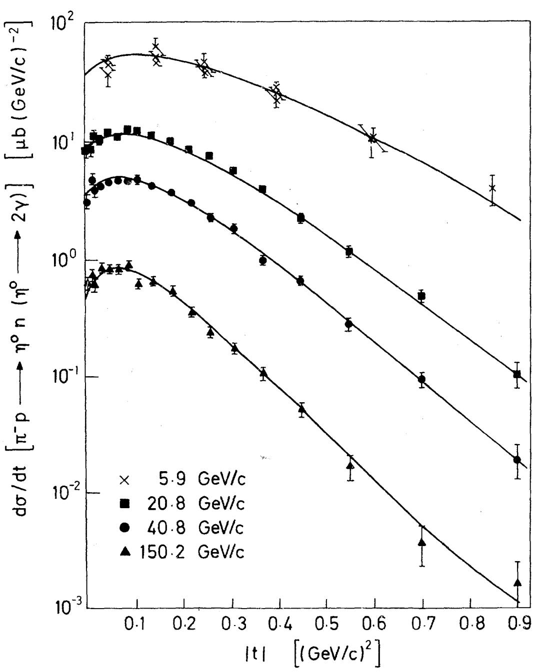


FIG. 9. $\pi^-p \to \eta^0n$ differential cross section compared to the non-Regge model (B2).

The final process which we fit is $\pi^-p \to \eta^0n$ and although the data are not significantly better than in the above two processes, it is a relatively simple process. A_2' contributions are very much smaller usually than ρ' contributions at these energies and there are only two components, the A_2 and Q_{A_2} to determine. In particular, if the A_2 is EXD with the ρ only the Q_{A_2} has any real freedom and this is thus well determined. A good fit to the differential cross-section data is achieved in model (B2), Fig. 9. The polarization data put practically no constraints on the model. We will discuss the predictions for this process in the next section.

Thus in comparing the Regge-pole models with the Q models we find that only the models (B2) with "$\rho = A_2$" and "$\omega = f$" give a similar quality of fit to the data. The $t=0$ data and total-cross-section measurements are better fitted by the non-Regge model, whereas the KN charge-exchange processes are more difficult to fit. However, in this latter case the Regge-pole models cannot fit the data perfectly without additional exchanges (possibly ρ', A_2') so a real comparison between the models is difficult to make.

We conclude this section with a discussion of the Q contributions to the various quantum-number-exchange amplitudes. The Q contributions in model (B2) are given in Table II.

The similarity between Q_ρ and Q_{A2} is obvious, but because of the difference in crossing properties the EXD breaking characterized by the ratio $d\sigma/dt\,(\pi^-p \to \pi^0n)/d\sigma/dt\,(\pi^-p \to \eta^0n)$ is well described as we saw above (Fig. 5). The Q_ω term is very much stronger than the other two at small $|t|$, although β_ω is badly determined.

We should also note that $A_{Q_{A_2}}$, A_{Q_ρ} are approximately of the form [see Eq. (3)]

$$si^{\epsilon}\delta[\ln^2(s/s_0) - i\pi\ln(s/s_0)],$$

TABLE II. Q contributions to the various quantum-number-exchange amplitudes in model (B2). The errors quoted denote χ^2 changes of about 1%.

	Q_{A_2}	Q_ρ	Q_ω
β (mb GeV^{-1})	0.32 ± 0.01	0.54 ± 0.02	-1.73 ± 1.46
γ (mb GeV^{-1})	-0.14	-0.14	-1.13 ± 0.02
δ (mb GeV^{-1})	0.014	0.009	0.091 ± 0.003
λ (mb GeV^{-1})	2.94 ± 0.45	4.81 ± 1.66	27.2 ± 0.8

since $\beta \approx \gamma^2/4\delta$, and such a form (which has one parameter less) could have been used with no significant change in the quality of the fit.

Finally we show the EXD Regge-pole parameters of model (B2) in Table III [in the notation of Eq. (7)].

IV. PREDICTIONS

In order to distinguish between the Regge-pole models and those models with non-Regge terms at high energy we must find measurables that offer a clear difference between the two and which will be available experimentally in the near future. Clearly, since the new terms have very different behavior from the usual singularities that constitute the secondary exchanges, all quantities will begin to show differences as the energy increases. However, the differential cross sections and total-cross-section differences only begin to show some curvature away from the expected behavior at the upper end of the Fermilab energy range (as is obvious since any strong curvature would imply definite evidence of non-Regge behavior in its own right), with the exception of $\sigma_{K^-p} - \sigma_{K^+p}$, where some evidence of such an effect may be present. The percentage difference between the two sets of models for these measurables is quite small up to about 1000 GeV/c. For $d\sigma/dt$ we consider only small $|t|$ since the large-$|t|$ behavior of the non-Regge terms is basically an unknown factor.

The prediction for $\sigma_{K^-p} - \sigma_{K^+p}$ can be seen in the two models in Fig. 6. In the Q model this quantity has a crossover at $P_{\text{lab}} = 450$ GeV/c. Projected experiments on $d\sigma/dt$ and σ_{tot} at such high energy for the KN system are unlikely in the near future.

More sensitive, however, to the inclusion of singularities at $J = 1$ are the various polarizations.[18] These have not yet been measured at Fermilab, and it seems likely that evidence of these new terms at high energy would be better discovered here than in later experiments on differential and total cross sections.

We thus compare predictions for the LSP and 5PM which are somewhat similar, with the predictions for the non-Regge model (B2) as described above, which has a comparable χ^2 to the two more conventional models. The J_0-type residue is used throughout, since we believe that any problems encountered in $K^-p \to \bar{K}^0 n$ at 8 GeV/c are probably due to a still important ρ' or A_2' contribution[7] which will certainly be less important as far as high-energy predictions are concerned. However, it should be remembered that the predictions for KN CEX are somewhat uncertain, although qualitatively they will remain the same at high energy.

Because we do not have a good idea as to the form factors in the non-Regge terms at large $|t|$, we concentrate in our predictions on the small-$|t|$ region.

The predictions for all the polarizations are shown in Figs. 10(a)–10(e). In the elastic polarizations, sensitive as they are to interference between the dominant Pomeron and the lower-order terms, we found little difference in the model predictions [Figs. 10(a) and 10(b)]. The range of predictions in the Regge-pole model depends on the relative size of the B amplitude which is not well pinned down by the data at present. For example, the LSP model gives a polarization of up to 20% from $P_{\text{lab}} = 100$ to 300 GeV/c for both $K^{\pm}p$, whereas 5PM gives a small polarization consistent with zero. Comparing this with Eq. (5) we can see that the coupling of the Pomeron pole to the B amplitude is extremely small, and this explains the predicted difference at high energy. From $d\sigma/dt$ alone it is not possible to determine the relative strengths of A and B and polarization measurements at Fermilab energies will clearly be useful here. The non-Regge models predict a fairly small (< 10%) positive polarization lying on the whole within the range of possible values of the 5PM and LSP model. Thus $K^{\pm}p$ polarizations will probably offer more a test of the B/A ratio than of unconventional effects in the non-Pomeron-exchange amplitudes.

In Figs. 10(c) and 10(d) we show the predictions for the two charge-exchange processes from 25 to 300 GeV/c. There are now clear differences between the predictions for "Regge" models (LSP and 5PM) and the non-Regge model (B2). In the two Regge models the polarization for $K^+n \to K^0 p$ is positive over the range $0 < |t| \lesssim 0.7$, whereas in $K^-p \to \bar{K}^0 n$ it is negative. In both cases $|P| \sim 30\%$ at its peak and is practically independent of energy over the whole energy range. We see that the Q-model predictions are of *opposite sign at small* $|t|$ to the Regge predictions, although at 25 GeV/c they are somewhat similar over the rest of the t range. For example, in $K^+n \to K^0 p$ the polarization can be -40% in the non-Regge model at $t = -0.05$ in contrast to the $+10\%$ of the Regge models. The difference is even more dramatic for $K^-p \to \bar{K}^0 n$ at very high energy where $P = +60\%$ is predicted at 300 GeV/c, which again contrasts with the -30%

TABLE III. EXD Regge-pole parameters of model (B2) [in the notation of Eq. (7)].

	$\rho = A_2$	$\omega = f$
C_+	1.75	4.27
C_-	32.5 ± 0.4	17.7 ± 7.9
α_0	0.47	0.52
α'	0.92 ± 0.03	0.61 ± 0.16

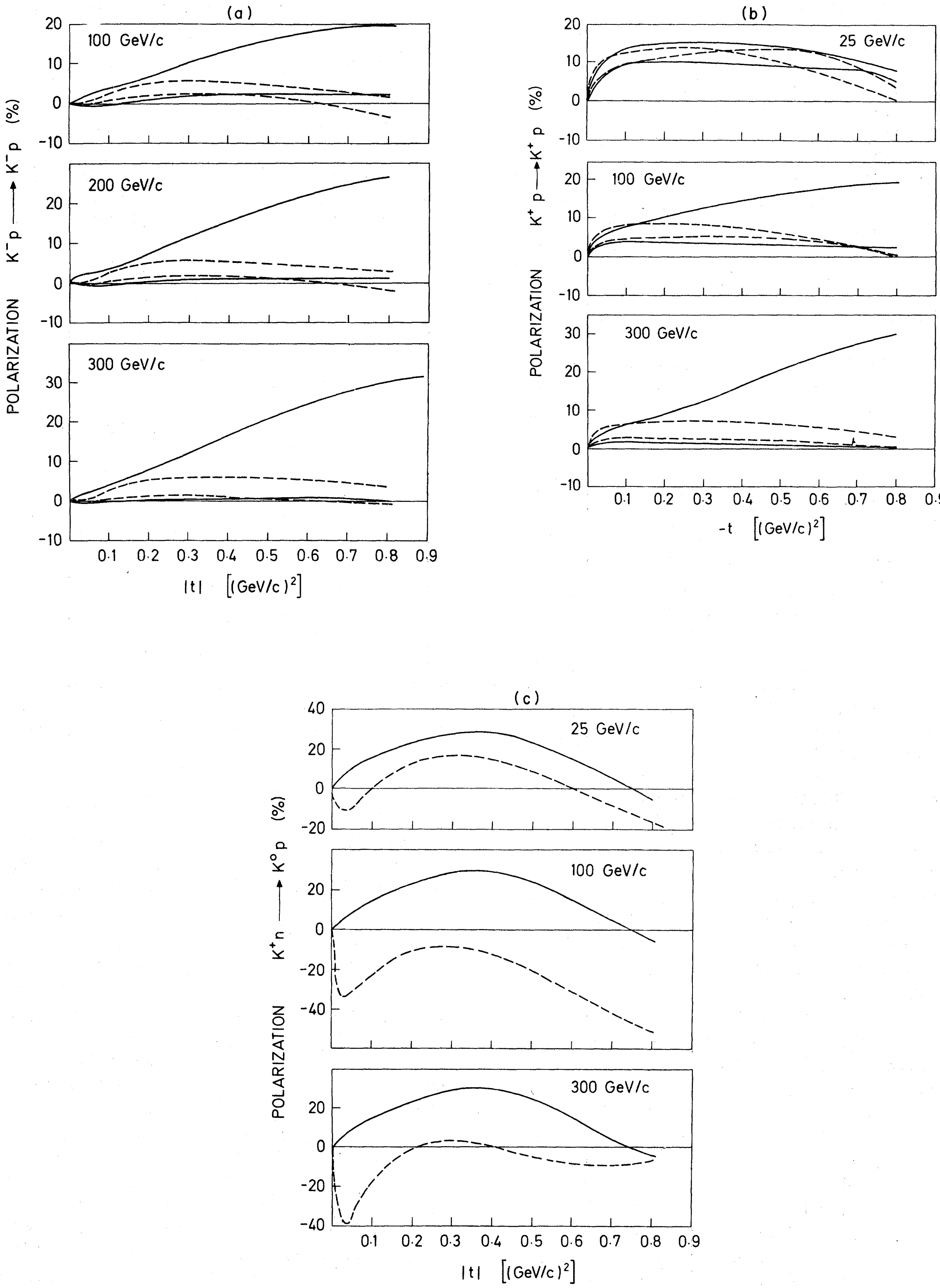
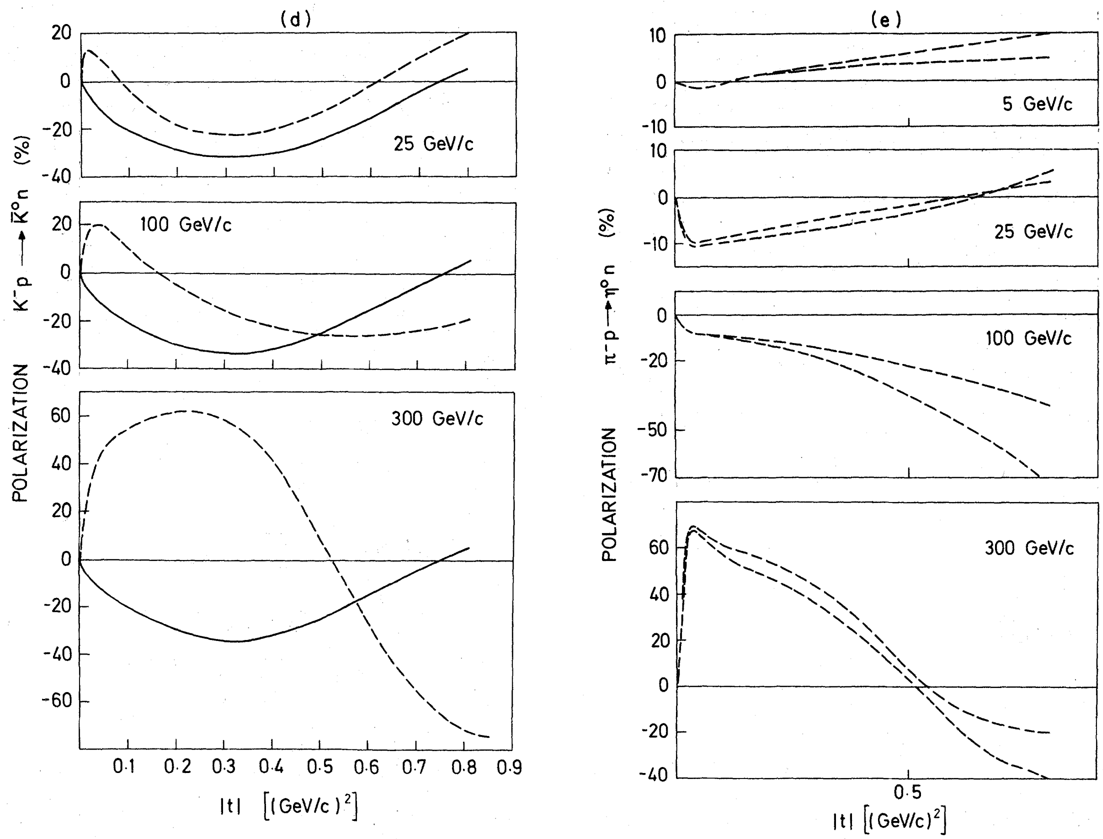


FIG. 10. (*Continued on following page*).



FIGs. 10. (a)–(e) Predictions for the polarizations of $K^-p \to K^-p$, $K^+p \to K^+p$, $K^-p \to \bar{K}^0 n$, $K^+n \to K^0 p$, and $\pi^-p \to \eta^0 n$, respectively. The solid curves denote Regge-pole models, dashed curves denote non-Regge models. If two curves of the same type are plotted on one graph these represent the spread of predictions in the relevant model, as given by our variety of fits.

of the more orthodox models. In particular, we note that the hallmarks of non-Regge behavior are large polarizations and fairly rapid sign changes in this energy range.

For η^0 production the Regge-pole model gives zero polarization and below 100 GeV/c the non-Regge models do not give any sizable polarization ($|P|<10\%$) for small $|t|$. However, just above $P_{\text{lab}}=100$ GeV/c there is a change in sign and the polarization becomes large and positive. This can be seen in Fig. 10(e) where the $\pi^-p \to \eta^0 n$ polarization at 300 GeV/c is $+70\%$ in the small-$|t|$ region and falls rapidly, with a zero at $|t|=0.5$, and becomes negative at larger $|t|$; this behavior clearly distinguishes it from the Regge pole.

So the best places to look for unconventional effects near $t=0$ are the KN charge-exchange processes and η^0 production, provided that ρ', A_2' complications do not unduly influence our parameters at high energy. This is as one might expect. The elastic polarization is not a good test of non-Regge effects, although it will enable a better determination of the comparative roles of the B and A' amplitudes in these processes.

V. CONCLUSIONS

In this paper we have compared several kinds of models with the data on $K^\pm p$ elastic, $K^\pm N$ CEX, and $\pi^-p \to \eta^0 n$ scattering. The most conventional of these models, which consisted of the five simple Regge poles P, f, ρ, ω, and A_2, was seen to be surprisingly good except for certain discrepancies with the data in and near the forward direction. By considering a Pomeron which is of $\log^2$ type some improvements can be seen in the elastic differential cross section, but certain difficulties still remain here and in the total-cross-section differences.

Therefore we studied what type of high-energy terms could be added to all the secondary exchanges for an accurate description of the data, while at the same time we maintained certain theoretically desirable restrictions (as for example EXD) on the Regge-pole parameters. We tried a class of new terms which asymptotically dominate over the Regge poles. Out of this class we found that quadratic forms in $\ln s$ were favored by the forward data. These terms are successful in explaining the apparent breaking of EXD between A_2- and ρ-quantum-number-exchange amplitudes.

Although in describing the present data no substantial difference between the conventional and unconventional models appears, the predictions for the polarizations clearly distinguish between them. We have seen that the best place to look for unconventional effects near $t=0$ are the KN charge-exchange processes and η^0 production. To give one example, the polarization in $K^-p \to \bar{K}^0 n$ at $P_{\text{lab}} = 300$ GeV/c and small $|t|$ is large and positive in the unconventional models, while in the conventional models it is negative. Polarization measurements at Fermilab for the charge-exchange processes would therefore be especially interesting.

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