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Polarization and Dip-Bump Structure in π^-p Charge-Exchange Scattering

S. Kogitz and R. K. Logan
Physics Department, University of Toronto, Toronto 5, Ontario, Canada
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We show that the new π^-p charge-exchange polarization and differential cross-section data at large angles can be explained in terms of a simple model which includes a ρ Regge pole plus a background term which one may interpret as either a secondary pole or a cut. We show that the rise after the dip is primarily due to the background term and not the spin-flip Regge term recovering from α passing through zero near $t=-0.6$ GeV^2. We discuss the effect of this insight on dip systematics.

The first measurements[1,2] of π^-p charge-exchange (CEX) scattering indicated[3] that this reaction is dominated by single-ρ-Regge-pole exchange. Subsequent measurements of polarization[4] indicated that another term is contributing, which some took as evidence for a second Regge pole, the ρ',[5-7] and others as evidence for a cut.[8,9] As there is no way of discerning which of these two models is correct on the basis of presently available experimental data, we plan to use here a simple model which includes the ρ Regge pole plus a background term which can be considered to be a secondary pole or cut depending on whether we parametrize the energy dependence of the background term with $(s/s_0)^{\alpha_{\rho'}}$ or $[\ln(s/s_0)]^{-1}$.

One of the interesting features of the differential cross section is the dip near $t=-0.6$ GeV^2 followed by a bump. This structure has been attributed to the fact that the α factor multiplying the spin-flip amplitude passes through zero near $t=-0.6$ GeV^2. Because of factorization one expects to see this same dip-bump structure in other reactions in which the ρ is exchanged, such as $\pi N\to\omega N$ or $\gamma N\to\pi N$. This is not always the case, however, and a great deal of attention has been given to explaining why a dip occurs for some reactions and not for others. Bander and Gotsman[10] correlate the presence or absence of a dip with an α^2 or α factor, respectively, claiming that $|\alpha^m\tilde{\beta}s^\alpha+f_{\text{BG}}|^2\approx|f_{\text{BG}}|^2+2\alpha^m\tilde{\beta}s^\alpha f_{\text{BG}}$ near $\alpha=0$ will only give a dip for $m=2$. We have investigated this point further and showed that if both βs^α and f_{BG} are exponentially decaying in t, then no matter what power of α one uses one will not obtain a dip because the exponential t dependence of $\tilde{\beta}s^\alpha$ and f_{BG} wins out over the power behavior of α. It is our contention that the dip is due to the α factor but that the rise above the dip and the maximum near $t=-1$ GeV^2 are due primarily to the background term and not to the ρ spin-flip term recovering from α passing through zero. We have therefore considered a simple model incorporating this feature which, with a minimum of free parameters, can explain the present experimental data on π^-p CEX scattering, including the very recent measurements at large angles of both the differential cross section[11] and the polarization.[12]

In our analysis we will make use of the amplitudes defined by Singh.[13] The differential cross section is given by

$$\frac{d\sigma(s,t)}{dt}=\frac{1}{\pi s}\left(\frac{M}{4k}\right)^2\left|\left(1-\frac{t}{4M^2}\right)|A'|^2-\frac{t}{4M^2}\left(\frac{4M^2p^2+st}{4M^2-t}\right)|B|^2\right|, \tag{1}$$

the difference of the π^-p and π^+p total cross sections by

$$\Delta\sigma_{\text{tot}}(s)=\sqrt{2}\,\text{Im}A'(s,t=0)/p, \tag{2}$$

and the polarization by

$$P(s,t)=-\frac{\sin\theta}{16\pi\sqrt{s}}\frac{\mathrm{Im}A'B^*}{d\sigma/dt}, \tag{3}$$

where p is the pion lab momentum; $\sqrt{s}$, k, and θ are the center-of-mass energy, momentum, and angle; and M is the nucleon mass. The Regge contribution to the A' and B amplitudes is given by

$$A'_{\mathrm{Regge}}=\alpha\xi(\alpha)\beta(1+6t)(s/s_0)^{\alpha}(\tan\tfrac{1}{2}\pi\alpha+i), \tag{4}$$

$$B_{\mathrm{Regge}}=\alpha\xi(\alpha)\tilde{\beta}(s/s_0)^{\alpha-1}(\tan\tfrac{1}{2}\pi\alpha+i), \tag{5}$$

where $\xi(\alpha)=(\alpha+1)(\alpha+2)(\alpha+3)$.

We wish to create as simple a model as possible with a minimum number of free parameters. We therefore assume the ρ Regge pole lies on a straight-line trajectory, $\alpha_\rho=\alpha_\rho(0)+\alpha_\rho' t$. We also assume that the residues are given by constants. Note, however, the inclusion in Eq. (4) of the $1+6t$ factor, which was inserted to provide the well-documented crossover effect. Since we believe that the ρ and A_2 are exchange-degenerate Regge poles, we have multiplied both the helicity-flip and -nonflip residues by an $\alpha_\rho(t)$ factor. There are five free parameters, then, describing the ρ-Regge-pole contribution. They are the two residue parameters β and $\tilde{\beta}$, the two trajectory parameters $\alpha_\rho(0)$ and α_ρ', and the scale factor s_0.

We now turn to the background term, which we assume contributes principally to the A' amplitude since the polarization arises from the interference of the nonflip background amplitude with the spin-flip Regge amplitude. We assume the contribution to A' takes the form

$$A'_{\mathrm{BG}}=K\exp\{-[a+b(t-t_0)^2]^{1/2}\}\left(\frac{s}{s_0}\right)^{\alpha_{\rho'}}\frac{1-e^{-i\pi\alpha_{\rho'}}}{\sin\pi\alpha_{\rho'}},$$

where K, $\alpha_{\rho'}$, a, b, and t_0 are all free parameters to be determined. The energy dependence of our background term is that of a fixed pole. We choose this form because it minimizes the number of free parameters. We have checked that a moving pole or cut would give basically the same results if we choose the same t dependence. We determine the ten free parameters of our model using differential cross-section and total cross-section data exclusively. We found that the following parameters gave the best agreement with the data as shown in Fig. 1:

$\beta=17\ \mu b^{1/2}$, $\tilde{\beta}=790\ \mu b^{1/2}\,\mathrm{GeV}^{-1}$, $s_0=0.51\ \mathrm{GeV}^2$,

$K=-719\ \mu b^{1/2}$, $\alpha_\rho(0)=0.50$, $\alpha_\rho'=0.81\ \mathrm{GeV}^{-2}$,

$a=0.09$, $b=2.8\ \mathrm{GeV}^{-4}$, $t_0=-1.04\ \mathrm{GeV}^2$,

$\alpha_{\rho'}=-0.47$.

Our model explains the most recent large-t measurements[11] of the differential cross section at $p_{\mathrm{lab}}=3.67$ GeV/c and 4.83 GeV/c. We only considered data for $|t|<\frac{1}{2}|t_{\max}|$, where $t_{\max}$ is the value of t corresponding to $u=0$, since we felt that only for this range could we ignore u-channel effects. Having determined the parameters of our model, we now predict the large-angle polarization recently measured at 5 and 8 GeV by Bonamy *et al.*[12] (See Fig. 2.) While these results are preliminary, we wanted to include them in order to separate our model from a number of others which do not presently accommodate this new information. We might add that we only learned of these new polarization data after we had completed our

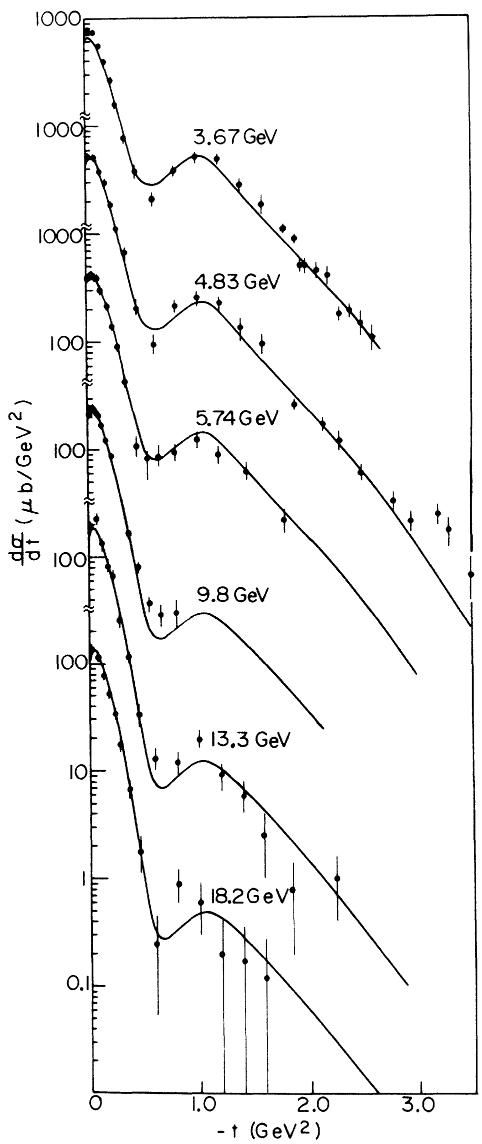

FIG. 1. Regge-pole-plus-background fit to the $\pi^- p$ charge-exchange differential cross section at $p_{\mathrm{lab}}=3.67$, 4.83, 5.74, 9.8, 13.3, and 18.2 GeV/c.

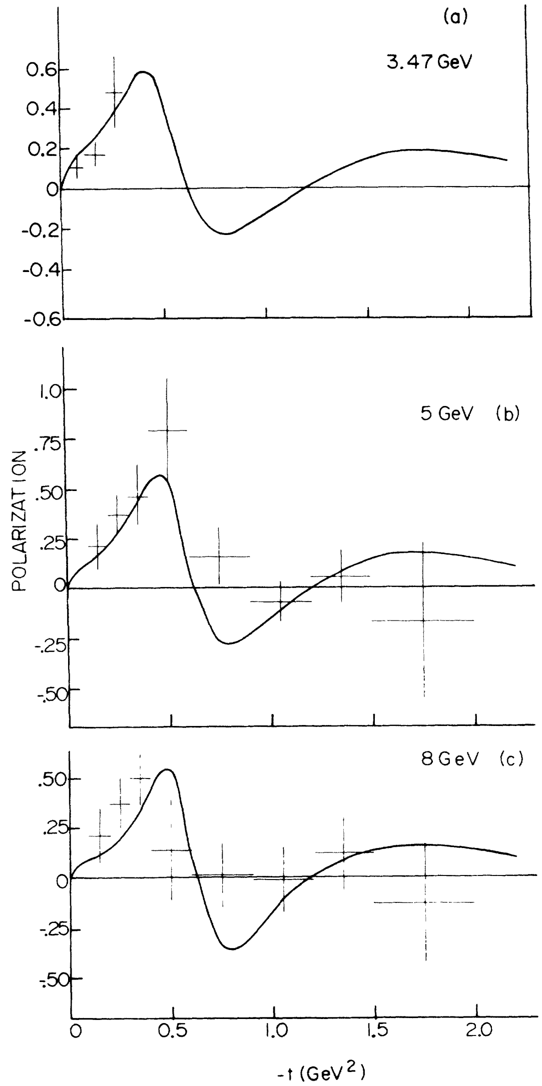

FIG. 2. Regge-pole-plus-background fit to (a) $\pi^- p$ CEX polarization at $E = 3.47$ GeV; (b) $\pi^- p$ CEX polarization at $E = 5$ GeV; and (c) $\pi^- p$ CEX polarization at $E = 8$ GeV.

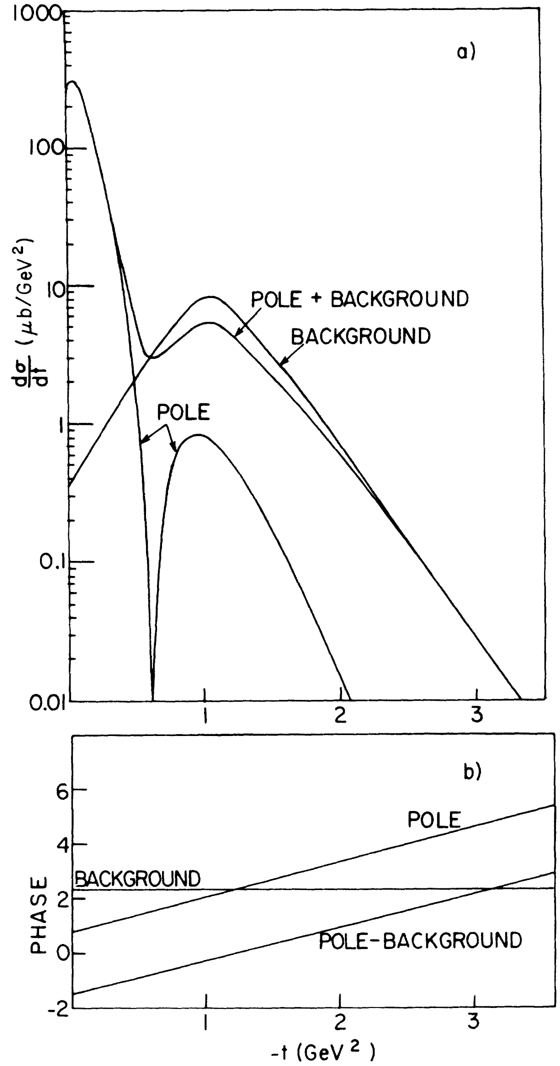

FIG. 3. (a) Contributions of pole and background to $\pi^- p$ charge-exchange differential cross section at $p_{\rm lab} = 8$ GeV/c. (b) Phases of pole and background and their difference in $\pi^- p$ CEX scattering.

analysis of the differential cross-section and polarization data.[4]

The polarization arises from the interference of the $B_{\rm Regge}$ and $A'_{\rm BG}$ terms whose phases are $\frac{1}{2}\pi(1-\alpha_\rho)$ and $\frac{1}{2}\pi(1-\alpha_{\rho'})$, respectively. The first zero in polarization occurs because $B_{\rm Regge} \to 0$ as $\alpha_\rho \to 0$. The second zero at $t = -1.2$ GeV^2 occurs, however, because the difference of the two phases, $\frac{1}{2}\pi(\alpha_{\rho'} - \alpha_\rho)$, passes through zero at this value of t. On the basis of this we predict future zeros of the polarization at $t = -3.1$ GeV^2 (where $\alpha_\rho = -2$) and at $t = -3.7$ GeV^2 (where $\alpha_{\rho'} - \alpha_\rho = 2$).

The main features of our model are the following:

(1) For small t the scattering amplitude is dominated by single-Regge-pole exchange and for large t by the background term. The pole and background phases and contributions to the differential cross section are displayed in Fig. 3.

(2) The dip near $t = -0.6$ GeV^2 is due to the α_ρ factors going through zero. If one removes the α_ρ factor, however, and uses the above parameters, the dip disappears but there is still a shoulder at $t = -1$ GeV^2.

(3) The rise above the dip is due to the form we choose for the t dependence of the background, $e^{-[a+b(t-t_0)^2]^{1/2}}$. We tried obtaining the maximum at $t = -1$ GeV^2 using a pure exponential form for

the background term and found we could not achieve a bump even if we replaced the α_ρ factor with an α_ρ^2. This calls into question the Bander and Gotsman[10] approach to dip systematics, which is based on the concept that an α_ρ^2 factor gives rise to a dip while an α_ρ factor does not. While we agree that an α_ρ factor is necessary for a dip, what is crucial is the t dependence of the background term rather than the power of the α_ρ factor.

(4) The background is represented by a fixed-pole singularity. A least-squares fit was attempted in which the slope of the ρ' was allowed to vary, and the best value of χ^2 was obtained with $\alpha_{\rho'}' = 0.002\ \mathrm{GeV}^{-2}$.

We might add that, within the framework of our model, the absence of a second bump in the reaction $\pi^- p \to \eta n$ up to $t = -1\ \mathrm{GeV}^2$ is consistent with the absence of polarization in this t range as recently measured by Bonamy *et al.*[12]

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