Double-Regge-Pole Analysis of the Reaction $K^- p \to K^{*0}(890)\pi^- p$ at 7.3 GeV/c*

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We apply the double-Regge-pole model to the final state $K^{*0}(890)\pi^- p$. Reasonable fits to the data are obtained by using the matrix element corresponding to exchange of the pion and Pomeranchukon trajectory.

THE double-Regge-pole model has so far been successful in describing reactions with three-body final states such as $pp \to \Delta^{++} p\pi^-$,[1] $pp \to pn\pi^+$,[2] and $\pi^- p \to \rho^0 \pi^- p$.[3] In this paper we apply the same model to the reaction $K^- p \to K^{*0}(890)\pi^- p$ at an incident K^- momentum of 7.3 GeV/c. We have examined all the invariant-mass, invariant-momentum-transfer, and angular distributions. Although they may not be kinematically independent of one another, it is found that certain distributions are more sensitive to a particular exchange mechanism or a model parameter. We believe, therefore, that, in order to adequately test the theoretical model, it is necessary to examine all the different distributions. It is the aim of this paper to show that essentially the same range of parameters as that found in previous works gives reasonable fits to all the distributions from our experimental data. In particular, the double-Regge-pole model gives the best over-all description of the low-mass $K^{*0}\pi^-$ enhancement including the angular distributions in the $K^{*0}\pi^-$ rest system than was hitherto possible with Deck-type calculations.[4]

The data for this study come from a portion of 150 000 pictures taken in the BNL 80-in. hydrogen bubble chamber exposed to a 7.3-GeV/c K^- beam at the AGS. 1707 events of the type $K^- p \to K^- \pi^+ \pi^- p$ have been processed, representing 2.2 ± 0.4 events/μb. Our analysis for the reaction $K^- p \to K^{*0}\pi^- p$ is based on a sample of 303 events which satisfied the following selection criteria:

$$0.86\ \text{GeV} < M(K^-\pi^+) < 0.94\ \text{GeV},$$
$$0.025\ (\text{GeV}/c)^2 < -t(p \to p) < 0.5\ (\text{GeV}/c)^2,$$
$$-t(K \to K^*) < 1.0\ (\text{GeV}/c)^2,$$
$$M(\pi^- p) > 1.34\ \text{GeV},$$

where $M(K^-\pi^+)$ stands for the effective mass of the $K^-\pi^+$ system, and $t(p \to p)$ for the square of the invariant momentum transfer between the incident and the outgoing proton. The lower cut on $-t(p \to p)$ has been introduced to eliminate the possible scanning bias that may be present for events with short stopping protons. Events satisfying the above selection criteria are free of contamination from other processes; we have examined the distributions in $M(\pi^+ p)$ and $M(\pi^+\pi^-)$ for these events and found little evidence of N^{*++} or ρ^0 contamination.

The differential cross section for the reaction $K^- p \to K^{*0}\pi^- p$ is given by

$$d\sigma = (2\pi)^{-5}(4F_I)^{-1}(\sum |m|^2)d\varphi_3, \tag{1}$$

where F_I is the usual flux factor and $d\varphi_3$ is the differential element of the invariant three-body phase space. $\sum |m|^2$ is the absolute square of the invariant amplitude, averaged over initial and summed over final spins.

The square of the amplitude for the double-Regge-pole model with Pomeranchukon and pion exchange [see Fig. 2(a)] is given by[5]

$$\frac{1}{4\pi}\sum |m|^2 = \left[\left(\frac{Q_{\pi p}}{s_0'}\right)^2 \sigma_T^2(\pi p) e^{a t_p}\right] \times \frac{(\pi\alpha_\pi')^2}{2(1-\cos\pi\alpha_\pi)}\left[G\left(\frac{Q_{K^*\pi}}{s_0}\right)^{2\alpha_\pi}\right], \tag{2}$$

where

$$\begin{aligned} Q_{\pi p} &= s_{\pi p} - t_{K^*} - m_p^2 + \tfrac{1}{2}(t_p + t_{K^*} - m_\pi^2),\\ \alpha_\pi &= \alpha_\pi'(t_{K^*} - m_\pi^2),\\ G &= (g_{K^*}^2/4\pi)[m_{K^*}^2 - (m_K + m_\pi)^2] \times [m_{K^*}^2 - (m_K - m_\pi)^2]/m_{K^*}^2,\\ Q_{K^*\pi} &= s_{K^*\pi} - t_p - m_K^2 + (t_p + t_{K^*} - m_\pi^2) \times (t_{K^*} + m_K^2 - m_{K^*}^2)/(2t_{K^*}). \end{aligned} \tag{3}$$

Here $s_{\pi p}$ is the square of the invariant mass of the $\pi^- p$ system, i.e., $s_{\pi p} = M^2(\pi^- p)$. We have employed a shorthand notation for the invariant momentum transfers, i.e., $t_{K^*} = t(K \to K^*)$ and $t_p = t(p \to p)$. α_π is the pion trajectory assumed to be linear in t_{K^*} as shown in (3), and the Pomeranchukon trajectory is assumed to be

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[5] The form of the matrix element is the same as that used by M. L. Ioffredo *et al.* (Ref. 3), which was originally suggested to them by E. L. Berger.

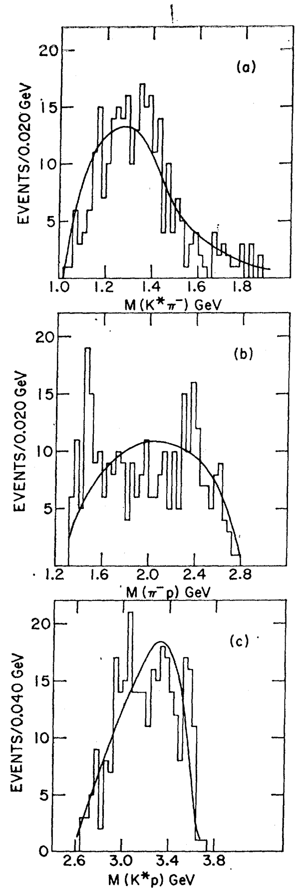

FIG. 1. Effective-mass spectra. Curves shown have been obtained by using the matrix element (2).

flat, i.e., $\alpha_P \approx 1$. Note that, for large $s_{\pi p}$,

$$Q_{\pi p}{}^2 \approx \lambda_0 \equiv [s_{\pi p}-(m_p+m_\pi)^2][s_{\pi p}-(m_p-m_\pi)^2].$$

The normalization in (2) is chosen so that as $t_{K^*} \to m_\pi{}^2$, (2) approaches the conventional one-pion-exchange (OPE) model expression[6] provided that $(Q_{\pi p}/S_0')^2$ is replaced by λ_0.[7]

The matrix element (2) contains six constants, three of which have been fixed as follows[8]: $\sigma_T(\pi p)=29$ mb, $a=7.8$ GeV^{-2}, and $g_{K^*}{}^2/4\pi=1.654$. The two constants α_π' and s_0 have been varied in order to estimate the sensitivity of the model to these parameters; we found acceptable fits to our data for α_π' in the range 0.8–1.2 and for s_0 in the range 0.8–1.4. These values are in the same range as those found in pp and πp interactions.[1–3] The theoretical curves[9] drawn in all the figures were obtained by setting $\alpha'=1.0$ GeV^{-2} and $s_0=1.0$ GeV.[2] Note that s_0' is merely a multiplicative parameter which may be determined by simply normalizing the total cross section to the experimental value. If it is arbitrarily chosen to be 1.0, we obtain 61 μb for the theoretical total cross section, to be compared with the experimental value of 138 ± 25 μb.

Figures 1–3 give various invariant-mass, invariant-momentum-transfer, and angular distributions. The curves drawn in each figure are the theoretical predictions normalized to the total number of events. Figure 1(a) shows that the low-mass $K^{*0}\pi^-$ enhancement is well described by the model. The mass and width predicted by the model are 1.28 and 0.35 GeV, respectively. It appears that the description of Pomeranchaukon exchange by a form analogous to that of the conventional diffractive πp scattering [the first square brackets in (2)] does not adequately describe the experimental $M(\pi^-p)$ distribution [Fig. 1(b)]. Of course, one expects that a diffractive πp scattering description is valid only for large values of $M(\pi^-p)$; we compared our data with the model by making a cut in $M(\pi^-p)$ at 1.8 GeV and found that the agreement did not substantially improve.[10] Any future improvement in the double-Regge-pole model may have to include exchanges other than Pomeranchukon at the nucleon vertex.

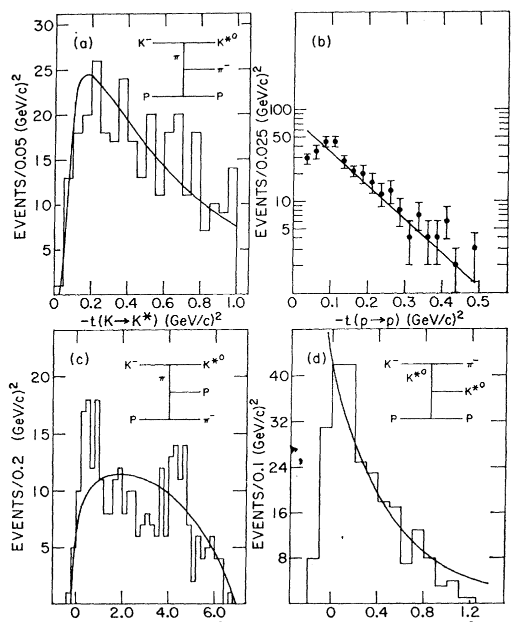

FIG. 2. Momentum-transfer distributions. Curves shown have been obtained by using the matrix element (2).

[6] The OPE-model formula is derived by using the on-mass-shell pion exchange and diffractive πp scattering, whose normalization is given by the optical theorem.

[7] We have tried an alternative formula which exactly approaches the OPE calculation by replacing $Q_{\pi p}{}^2$ in (2) by $\lambda_0 Q_{\pi p}{}^2/[Q_{\pi p}]_{t_{K^*}=m_\pi{}^2}$. The resulting distributions did not change appreciably from those obtained by using the matrix element (2).

[8] $\sigma_T(\pi p)$ is the total π^-p cross section at high energy; a is the experimental slope of π^-p elastic scattering at high energy; $g_{K^*}{}^2/4\pi$ is the coupling constant for the decay $K^{*0}\to K^-\pi^+$.

[9] The Monte Carlo program FOWL was used to generate the theoretical curves.

[10] We found, however, that the theoretical and experimental $\varphi(K^*\pi^-)$ distributions [see Fig. 3(b)] were in somewhat better agreement. We have also tried using an expression proportional to the on-mass-shell πp scattering data instead of the first square brackets in (2); there was no improvement in the fit.

Not all the momentum transfer distributions in Fig. 2 are kinematically independent of each other. However, certain momentum-transfer distributions may be more sensitive to a particular exchange mechanism than others. Three different exchange processes that may be important for the reaction $K^-p \rightarrow K^{*0}\pi^-p$ are shown in Figs. 2(a), 2(c), and 2(d). The momentum-transfer distributions in each of these figures should peak at low values, if the corresponding exchange diagram is the dominant process. The curves drawn in Fig. 2 are those predicted by the matrix element (2), which corresponds to a Pomeranchukon and pion exchange process [see Fig. 2(a)]. We see that it is not necessary to consider other types of exchange mechanisms in order adequately to describe our data.[11] The slope of the $-t(p \rightarrow p)$ distribution [Fig. 2(b)] is about 8.5 GeV^{-2} for both the experimental and theoretical distributions. We note that input to the slope was 7.8 GeV^{-2} [see Eq. (2)].

Four different angular distributions are compared with the theoretical curves in Fig. 3. In the $K^{*0}\pi^-$ rest system, the angles $\theta(K^*\pi)$ and $\varphi(K^*\pi)$ are the spherical angles of the outgoing K^{*0} in a coordinate system in which the z axis is along the incident beam direction and the y axis is along the production normal. The angles $\theta(\pi^-p)$ and $\varphi(\pi^-p)$ are defined in an analogous way. The predictions of the model are in good agreement with the data. In particular, the relatively flat $\cos\theta(K^*\pi)$ distribution (both theoretical and experimental) is consistent with previous results[12] that the $K^*\pi$ is predominantly in a $J^P=1^+$ state. Also, we have examined the angle between the normal to the decay plane of the $K\pi\pi$ system and the incident beam direction (evaluated in the $K\pi\pi$ rest system), as well as the angle between the π^- and π^+ in the $K^-\pi^+$ rest system. Both distributions (not shown) are also consistent with the $J^P=1^+$ interpretation for the low-mass $K^*\pi$ enhancement.[13]

We emphasize that, while the low-mass $K^*\pi$ enhancement is well reproduced by the double-Regge-pole model, it is by no means certain that the enhancement is totally of a kinematic origin. Rather, according to the principle of the Dolen-Horn-Schmid duality,[14] the low-mass $K^*\pi$ enhancement may well consist of closely spaced resonances, the semilocal average of which the double Regge pole model is able to describe. The duality principle also implies that the double-Regge-pole model can be expected to describe only the gross features of the experimental data. From this point of view, one may conclude that the description of narrow peaks such as those found in the $M(\pi^-p)$ spectrum [Fig. 1(b)] is beyond the scope of the double-Regge-pole model.

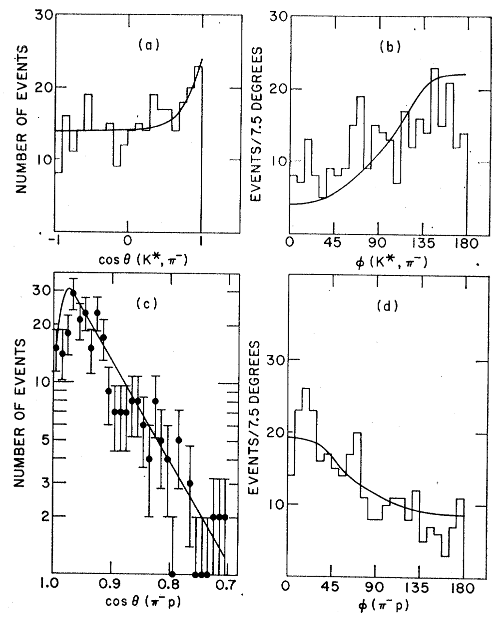

FIG. 3. Angular distributions. See text for the definition of these angles. Curves shown have been obtained by using the matrix element (2).

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[11] This is in contrast to the conclusions reached by P. J. Dornan *et al.*, Phys. Rev. Letters **19**, 271 (1967).

[12] J. Berlinghieri *et al.*, Phys. Rev. Letters **18**, 1087 (1967); G. Goldhaber, A. Firestone, and B. C. Shen *ibid.* **19**, 972 (1967).

[13] The $\cos^2\beta$ distribution, where β is the angle between the beam direction and the K^- in the $K^-\pi^+$ rest system, gave further evidence for the $J^P=1^+$ (s-wave) assignment.

[14] G. F. Chew and A. Pignotti, Phys. Rev. Letters **20**, 1078 (1968).