Precise Tests of Triple-Regge Theory from π^0 and η Inclusive Production in 100-GeV/c $\pi\pm p$ Collisions

A. V. Barnes, G. C. Fox, R. G. Kennett, and R. L. Walker
California Institute of Technology, Pasadena, California 91125

and

O. I. Dahl, R. W. Kenney, A. Ogawa, and M. Pripstein
Lawrence Berkeley Laboratory, Berkeley, California 94720
(Received 21 August 1978)

We present data on π^0 and η inclusive production from 100-GeV/c $\pi^{\pm}p$ collisions in the kinematic region $x \geqslant 0.7$ and $0 < -t \lesssim 4$ (GeV/c)^2. The results are in excellent agreement with the predictions of triple-Regge theory and we have extracted the ρ and A_2 trajectories out to $-t = 4$ (GeV/c)^2.

Regge theory is generally accepted as the correct theoretical description of two-body scattering at high energy.[1] The formalism can be quite complicated if one allows for the presence of both poles and cuts; further, there are only a few reactions which have just one trajectory exchanged and where a clean application of the theory is possible. The classic applications of Regge theory are the reactions

$$\pi^- p \to \pi^0 n, \qquad (1a)$$

$$\pi^- p \to \eta n, \qquad (1b)$$

which test the exchange of the ρ and A_2 trajectories, respectively.[1,2] The theory is simple and very successful. Triple-Regge theory describes inclusive reactions where the outgoing particle has kinematic parameters "near" those of the beam and target.[3] It has been extensively tested in leading-particle reactions, particularly $pp \to pX$,[4] where X means that any particles were produced in the final state. The theory is quite successful but, just as for the corresponding two-body processes (elastic scattering), there are many different exchanges allowed and no clean test has been possible.[5] In this paper, we present the first high-energy data on the triple-Regge analogs of (1), namely,

$$\pi^{\pm} p \to \pi^0 X, \qquad (2a)$$

$$\pi^{\pm} p \to \eta X, \qquad (2b)$$

and

$$\pi^- p \to \pi^0 X^0, \qquad (3a)$$

$$\pi^- p \to \eta X^0, \qquad (3b)$$

where X^0 means that only neutral particles were produced in the final state; we shall call this the neutral final state (NFS).

The data were taken with a 100-GeV/c pion beam at Fermilab using the photon detector originally built for the measurement of the corresponding exclusive processes (1). For the measurement of the full inclusive reactions (2), data were collected so as to cover the kinematic region $x \gtrsim 0.7$ and $0 < -t < 4$ (GeV/c)^2 with good acceptance and statistical precision. Here x is the fraction of the beam momentum carried off by the detected particle and t is the square of the momentum transfer between the incident beam and the detected particle. For the measurement of the NFS reactions (3), the trigger demanded no light in a box of scintillation counters placed around the target. The details of this experiment are described in Refs. 6 and 7.

For any of the reactions (2) and (3), triple-Regge theory predicts the form of the cross section to be

$$\frac{d^2\sigma}{dt\,dx} = G_e(t) s^{1-\tilde{\alpha}} (1-x)^{\tilde{\alpha} - 2\alpha_e(t)}, \qquad (4)$$

where the exchanged trajectory $\alpha_e(t)$ is expected to be the ρ and A_2 for π^0 and η production, respectively. For the full inclusive reactions (2),

$$\tilde{\alpha}_{\text{full}} = 1, \qquad (5)$$

corresponding to the $\rho\rho$ Pomeron or A_2A_2 Pomeron triple-Regge diagrams. The appropriate value of $\tilde{\alpha}$ for the NFS reactions (3) can be found from the s dependence of the total cross section for $\pi^- p \to$ all neutrals,[7] which gives

$$\tilde{\alpha}_{\text{NFS}} = -0.08 \pm 0.2. \qquad (6)$$

The x dependence of the π^0 cross section for representive t bins is shown in Fig. 1 for both the full inclusive and all neutral modes. The data have been corrected for acceptance, back-

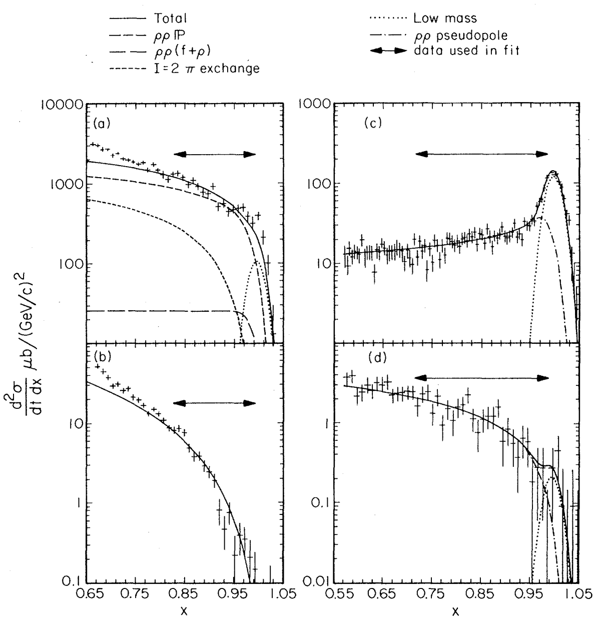

FIG. 1. Fits to the data for full inclusive π^0 production from π^- beam with $0.81 < x < 0.98$ for (a) $0.20 < -t < 0.30$ $(\mathrm{GeV}/c)^2$ and (b) $2.20 < -t < 3.00$ $(\mathrm{GeV}/c)^2$, with the contributions from the four terms discussed in text shown separately in (a). Fits to the all neutral-final-state π^0 production with $0.71 < x < 0.98$ for (c) $0.20 < -t < 0.25$ $(\mathrm{GeV}/c)^2$ and (d) $1.00 < -t < 1.20$ $(\mathrm{GeV}/c)^2$, with the triple-Regge term (marked $\rho\rho$ pseudopole) and low-mass resonance contributions also shown separately.

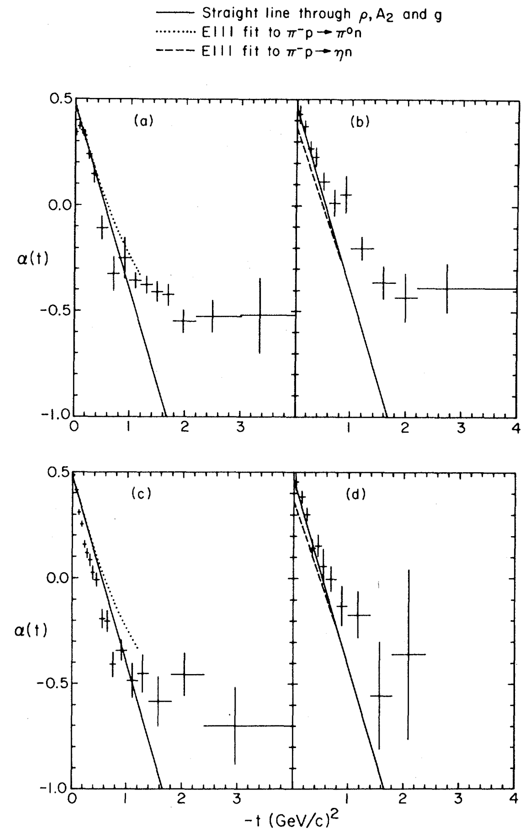

FIG. 2. (a) The ρ trajectory $\alpha_\rho(t)$ determined from fits to the $\pi^\pm p \to \pi^0 X$ cross sections with $0.81 < x < 0.98$. (b) The A_2 trajectory $\alpha_{A_2}(t)$ determined from fits to the $\pi^\pm p \to \eta X$ cross sections with $0.71 < x < 0.98$. (c) $\alpha_\rho(t)$ determined from fits to the $\pi^- p \to \pi^0 X^0$ cross section with $0.71 < x < 0.98$. (d) $\alpha_{A_2}(t)$ determined from fits to the $\pi^- p \to \eta X^0$ cross section with $0.71 < x < 0.98$.

ground, and analysis cuts, but, as described in Ref. 7, there are some biases in the NFS trigger for which corrections have not been made. Fitting these x-dependent cross sections with the theoretical form (4) gives the trajectory $\alpha_\rho(t)$ as a function of t. The curves shown in Fig. 1 come from the theoretical form (4) smeared with the energy resolution and the incident-beam momentum distribution. Figure 1 shows that the x dependence of the cross section changes strikingly with t; this corresponds to the decrease of $\alpha_\rho(t)$ with increasing $-t$, which is shown clearly in Fig. 2. Although the $\rho\rho$ Pomeron triple-Regge term is dominant in the process (2a), there are some additional contributions, which are shown in Fig. 1. There is the $\rho\rho(f+\rho)$ triple-Regge term, which has $\tilde{\alpha} \simeq 0.5$ but a rather small normalization. More important are the isospin-2 exchanges, which have been modeled using π exchange and checked against the $\pi^+ p \to \pi^- X$ measurements.[8] Note that this term is not present for η production. Also shown in Fig. 1 is the contribution of low-mass resonances, which are outside the region, $x \lesssim 0.98$, used for the fits.

Figure 2 shows the trajectories extracted from the data for the four processes (2) and (3) in the manner illustrated above for the full inclusive π^0 production. The full inclusive results come from simultaneous fits to the π^+ and π^- beam data since, in agreement with the theory, the π^+- and π^--induced cross sections are equal. The similarity between the four trajectories shown in Fig. 2 is very striking. It should be emphasized that the essentially identical trajectories for the all neutral-final-state and full-inclusive processes are determined from very different x distributions. These differ by the factor $(1-x)^{1.08}$ which follows from the different values of $\tilde{\alpha}$ in Eqs. (5) and (6). At low $-t$, the trajectories agree both with the results derived from the s dependence of the corresponding exclusive cross sections (1) and with the straight line through the ρ, A_2, and

g poles in the physical m^2-J plane. At $t \simeq -1$ $(\mathrm{GeV}/c)^2$, the trajectories all curve away from this line and flatten off at $t \simeq -0.5$ $(\mathrm{GeV}/c)^2$. Such a flattening is predicted by the constituent interchange model,[9] but this model predicts an asymptotic value of $\alpha_\rho = \alpha_{A_2} = -1$. Both this value and the predicted normalization $G(t)$ are inconsistent with our measurements.[6]

Figure 3 shows the residue functions $G_{\rho, A_2}(t)$ arising from the same fits as used for Fig. 2. Figures 3(a) and 3(c) show a dramatic dip in the π^0 residue function at $t \simeq -0.5$ $(\mathrm{GeV}/c)^2$. This is at the place where the ρ trajectory passes through zero and is predicted by the ρ signature factor present in the residue function.[6] The A_2 has the opposite signature from the ρ and this is consistent with there being no dip present in the η residue function shown in Figs. 3(b) and 3(d).

Our data have provided a stringent test of triple-Regge theory because only one exchange is dominant. At low $-t$, where we can compare our results to the exclusive measurements, the theory is successful for both the trajectories and the residue functions. The low $-t$ data suggest that simple Regge theory provides the dominant contribution to both the inclusive and exclusive reactions; there can be Regge cut terms but they are either small or exactly mimic the behavior of the pole term. At higher $-t \gtrsim 1.5$ $(\mathrm{GeV}/c)^2$, there is a striking change in the physics, with the trajectories becoming independent of $-t$. Any explanation of this should explain why the same behavior is seen in both all neutral and full-inclusive final states. In Ref. 6 we discuss the interpretation of the high $-t$ data in terms of constituent scattering.

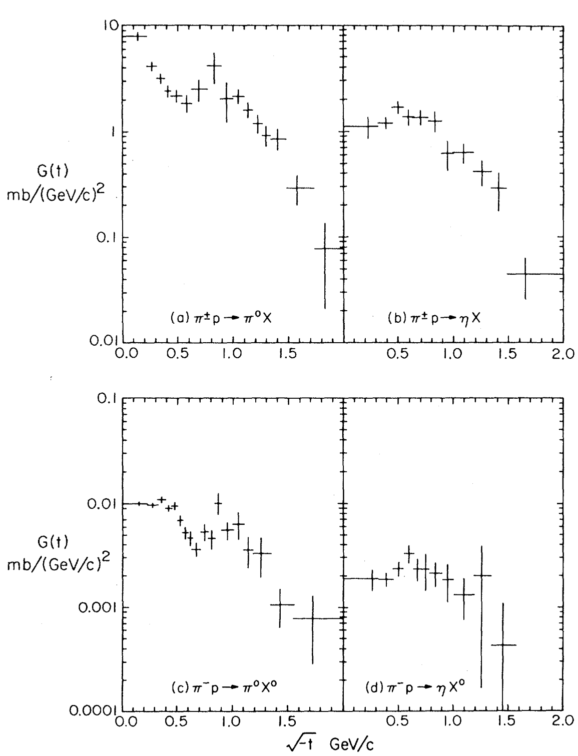

FIG. 3. The residue functions $G_{\rho, A_2}(t)$ determined from the same fits used in Fig. 2 and illustrated in Fig. 1.

We should like to thank A. V. Tollestrup, R. A. Johnson, D. J. Mellema, D. Hermeyer, A. E. A. Stone, and B. G. Cortez for help in setting up and analyzing this experiment. One of us (R.G.K.) would like to thank the Fannie and John Hertz Foundation for fellowship support. One of us (G.C.F.) would like to acknowledge receipt of an Alfred P. Sloan Foundation Fellowship. This work was supported in part by the U. S. Department of Energy under Contracts No. EY 76-C-03-0068 and No. W-7405-Eng-48.

[1]A. C. Irving and R. P. Worden, Phys. Rep. 34C, 117 (1977).

[2]A. V. Barnes *et al.*, Phys. Rev. Lett. 37, 76 (1976); O. I. Dahl *et al.*, Phys. Rev. Lett. 37, 80 (1976).

[3]A. H. Mueller, Phys. Rev. D 2, 2963 (1970), and 4, 150 (1971); R. D. Field and G. C. Fox, Nucl. Phys. B80, 367 (1974).

[4]J. Butler, in Brookhaven National Laboratory Report No. BNL-50598, edited by H. Gordon and R. F. Peierls, Proceedings of the American Physical Society Meeting, Division of Particles and Fields, Upton, New York, 1976 (unpublished); K. Abe *et al.*, Phys. Rev. Lett. 31, 1527 (1973); Y. Akimov *et al.*, Phys. Rev. Lett. 35, 766 (1975); M. G. Albrow *et al.*, Nucl. Phys. B108, 1 (1976); R. L. Anderson *et al.*, Phys. Rev. Lett. 38, 880 (1977).

[5]There have been previous tests of triple-Regge theory in the nondiffractive processes $pp \to \Lambda X$ [T. Devlin *et al.*, Nucl. Phys. B123, 1 (1977)] and $pp \to (\pi, K)X$ [J. R. Johnson *et al.*, Phys. Rev. Lett. 39, 1173 (1977) and J. Singh *et al.*, Nucl. Phys. B140, 189 (1978)]. Of these reactions, only $pp \to \pi^- X$ has a single-exchange interpretation in the triple-Regge formalism but this is baryon exchange (the Δ^{++}) which has always been harder to understand in a Regge picture than the meson exchanges of reactions (2) and (3).

[6]A. V. Barnes *et al.*, California Institute of Technology Report No. CALT-68-664, 1978 (to be published).

[7]A. V. Barnes *et al.*, California Institute of Technology Report No. CALT-68-667, 1978 (to be published).

[8]D. Cutts *et al.*, Phys. Rev. Lett. 40, 141 (1978).

[9]D. Sivers, S. J. Brodsky, and R. Blankenbecler, Phys. Rep. 23C, 1 (1976).