Brief Reports

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Constituent scattering at moderate $p_\perp$: The $\pi^- p \to \pi^0 X$ reaction

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The $\pi^- p \to \pi^0 X$ and $\pi^- p \to \eta X$ data of Barnes *et al.* at 100 GeV/c for $1.5 \le -t \le 4$ (GeV/c)^2 are analyzed using the Feynman-Field constituent (black-box) model. Good agreement is obtained for both the t and x distributions. We conclude that the apparent deviation from linearity at large $-t$ for the ρ and A_2 trajectories, as observed by the above experiment, is the result of the constituent scattering.

I. INTRODUCTION

In an experiment by Barnes *et al.*[1] on $\pi^- p \to \pi^0 X$ at 100 GeV/c, it was observed that the low-t data are fitted very well by the ρ Regge trajectory (the only one allowed in the t channel) via the triple-Regge mechanism. The trajectory is linear in t consistent with the exclusive-scattering data as well as with the positive-t region of the resonances.[2] However, at $-t \approx 1$ (GeV/c)^2, the trajectory begins to deviate from linearity and for $-t \ge 1.5$ (GeV/c)^2 Barnes *et al.*[1] find that the data can be fitted only if one assumes $\alpha_\rho(t)$ to be a constant ≈ -0.60. As stated earlier, this is not expected on the basis of the ρ behavior for t positive and small negative (and for exclusive scattering, for larger negative t's as well), where a single linear function suffices (see Fig. 1).[2]

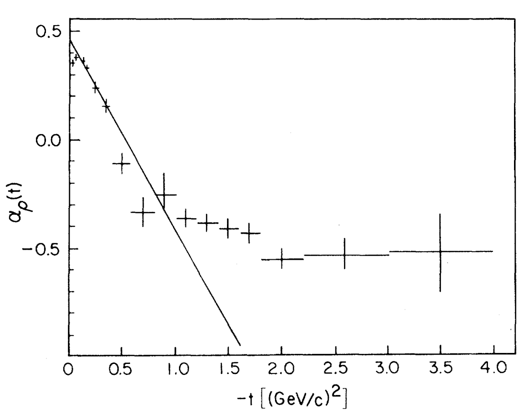

FIG. 1. The ρ trajectory determined from the triple-Regge analysis of Barnes *et al.* (Ref. 1) for 100-GeV/c $\pi^- p \to \pi^0 X$ data with $0.81 < x < 0.98$. The ρ trajectory from exclusive data (Ref. 2) is given by the solid line.

We explore here the possibility that it is the constituent hard-scattering phenomenon which is responsible for the $\pi^- p \to \pi^0 X$ data for $-t > 1.5$ (GeV/c)^2. In this picture, the ρ trajectory can continue to fall off linearly, disappearing, for practical purposes, at moderate and large negative t's, revealing a new kind of (hard) scattering phenomena.

The above remarks apply also to the A_2 trajectory vis-à-vis the $\pi^- p \to \eta X$ data of Barnes *et al.*[1]

In so far as the hard-scattering models are concerned, it is well known that the purely phenomenological black-box model of Feynman and Field[3,4] (hereafter referred to as FF1) works very well at moderate t's, at least for the $pp \to \pi^0 X$ inclusive cross section. We plan to use this model to explore whether it reproduces also the $\pi^- p \to \pi^0 X$ and $\pi^- p \to \eta X$ cross sections.

In the next section we briefly summarize the FF1 model and its predictions. Section III contains some concluding comments.

II. CONSTITUENT MODEL AND $d\sigma/dt\,dx$ FOR $\pi^- p \to \pi^0 X$

The differential constituent scattering cross section as given by the FF1 model is[3]

$$\frac{d\sigma}{d\hat{t}} = -\frac{A}{\hat{s}\hat{t}^3} , \tag{2.1}$$

where $\hat{s}$ and $\hat{t}$ are the appropriate constituent variables. This expression successfully explains the $pp \rightarrow \pi^0 X$ inclusive cross section at moderate $p_\perp$. Since it is the inclusive cross section which is of primary concern to us, we will use FF1 in our analysis of the $\pi^- p \rightarrow \pi^0 X$ cross section.

The FF1 model gives excellent agreement with the data of Barnes *et al.* in both x and t distributions and in absolute normalization (see Fig. 2 for x distribution). However, in recent years a convincing amount of experimental evidence has accumulated in favor of a linear rather than FF1's constant pion distribution function.[5,6] Therefore, we will incorporate several changes to the original FF1 model. We will use linear pion distribution functions, consistent with the counting rules,[7] given by

$$d^{\pi^-}(x) = \bar{u}^{\pi^-} = 0.75(1-x)/\sqrt{x} \tag{2.2}$$

for the valence quarks and

$$0.1(1-x)/x \tag{2.3}$$

for each of the sea-quark distributions.

We have also included smearing due to the $k_\perp$ fluctuations for the internal motion of the quarks.[8,9] This has been done in a manner similar to the modifications by Feynman, Field, and Fox,[8] where Eq. (2.1) is changed to

$$\frac{d\sigma}{d\hat{t}} = \frac{-A}{(\hat{s}+m_s^2)(\hat{t}-m_t^2)^3} \ , \tag{2.4}$$

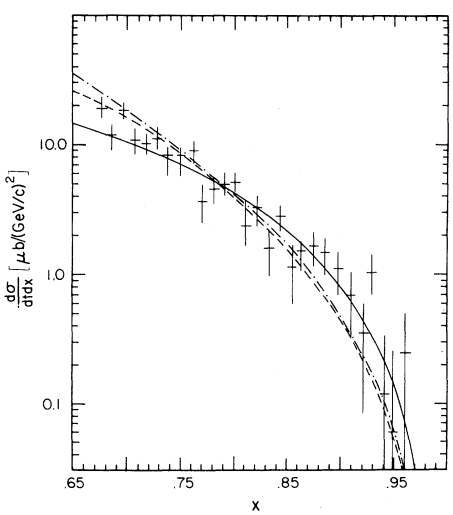

FIG. 2. $d\sigma/dt\,dx$ as a function of x for $3.0 < -t < 3.5$ $(\mathrm{GeV}/c)^2$ for 100 GeV/c $\pi^- p \rightarrow \pi^0 X$ (Ref. 1). The solid line is the triple-Regge fit of Barnes *et al.* (Ref. 1) to the data. The dashed line is the FF1 model prediction with the constant pion distribution function of FF1. The dashed-dot line is the prediction with linear pion distribution together with $k_\perp$ smearing (see text). The dashed-dot line is normalized to the solid line at $x = 0.8$.

where $m_s^2 = 6$ GeV^2, $m_t^2 = 2$ GeV^2, and $A = 2300$ mb GeV^6. For simplicity, only the $k_\perp$ effects of the two initial quarks have been included and confined to the original reaction plane. We have used a Gaussian distribution instead of the traditional exponential behavior with $\langle k_\perp \rangle$ of 330 MeV.[8] For the one-dimensional Gaussian which we are using here, this would correspond to $\langle k_\perp \rangle$ of $(1/\sqrt{2})$ (330) MeV.

Using the FF1 prescription, with the above changes one can obtain $d\sigma/dt\,dx$ for $\pi^- p \rightarrow \pi^0 X$ in the standard manner.[10]

Figure 2 shows the x distribution for $3.0 \leq -t \leq 3.5$ $(\mathrm{GeV}/c)^2$. The agreement with the data is very good. We obtain similar agreement for the $\pi^- p \rightarrow \eta X$ data of Barnes *et al.*[1] The agreement for the t distribution (not plotted here) is found to be equally good for both the reactions.

We note that the effect of smearing on $d\sigma/dt\,dx$ is to decrease the overall power of $(1-x)$—an effect which increases with increasing $\langle k_\perp \rangle$. It is, therefore, interesting to point out that the $k_\perp$ fluctuations can mimic a constant pion distribution even though the actual pion distribiuon may behave as $(1-x)$.

The triple-Regge formalism predicts[2]

$$\frac{d\sigma}{dt\,dx} = \beta(t)(1-x)^{1-2\alpha_\rho(t)} \ , \tag{2.5}$$

where $\alpha_\rho(t)$ is the ρ Regge trajectory. In order to fit the $\pi^- p \rightarrow \pi^0 X$ data for $-t > 1.5$ $(\mathrm{GeV}/c)^2$, Barnes *et al.* find that $\alpha_\rho(t) = -0.61$. Their fit is given by the solid line in Fig. 2. The clearest separation between FF1 and Regge models will occur when s is extremely large as evidenced by the different s behaviors of the two models.

We conclude this section with comments about the FF1 model: we are working in a region in $p_\perp$ which is somewhat small for the hard-scattering model to be completely reliable. One could partially rectify this aspect of the problem by modifying FF1 so as to fit the $pp \rightarrow \pi^0 X$ data down to $p_\perp \approx 1$ GeV/c. However, our purpose was not to introduce a new "black-box" model but rather to demonstrate that a model existing prior to this experiment gave good description without further adjustments. At larger values of $p_\perp$, where both FF1 and QCD models may be applied, both give similar x and t distributions of $\pi^- p \rightarrow \pi^0 X$.[11]

III. CONCLUSION

There are two possible alternatives one can pursue in order to reconcile the flat ρ trajectory for $-t \geq 1.5$ $(\mathrm{GeV}/c)^2$ with the constituent-model fit. One is that the ρ trajectory indeed flattens out and, therefore, the constituent picture and the ρ-trajectory picture are equivalent descriptions of the same phenomenon [for $-t \geq 1.5$ $(\mathrm{GeV}/c)^2$]. The other is that the ρ trajectory continues its linear behavior making negligible contribution for $-t \geq 1.5$ $(\mathrm{GeV}/c)^2$ but that the constituent hard-scattering model takes over in this t region.[12]

We prefer the latter alternative for two reasons: (i) on the basis of analyticity it is difficult to imagine a function which has a linear behavior for positive values of t (and small negative t) but which does not maintain the same linear behavior for larger negative t's, and (ii) for exclusive scattering, $\alpha_\rho(t)$ maintains a linear behavior for moderate to large negative t's.[2,12,13]

Thus the differential inclusive cross section can be divided into two separate t regions: low t's dominated by Regge poles, and moderate and large t's dominated by constituent hard scattering. What is interesting is that the moderate t values can be as low at $t \approx -1.5$ $(\mathrm{GeV}/c)^2$.

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[9] The fact that smearing is important at small transverse momentum has been pointed out in Ref. 4.

[10] In order to compare with Barnes *et al.* (Ref. 1), we convert the usual definitions of the kinematic variables to the ones specifically used by Ref. 1.

[11] D. Beavis, Ph.D. dissertation, University of California, Riverside, 1980 (unpublished).

[12] One could then interpret the constituent prediction as being equivalent to Regge *cuts*. The discrepancy with the linear α in exclusive scattering (e.g., $\pi^- p \to \pi^0 n$) could then be attributed to a more coherent phenomena inherent in any exclusive process.

[13] As stated earlier, the cleanest distinction between the two alternatives will occur when s is extremely large, as the two models (constituent and Regge) have very different s dependence.