Fermi National Accelerator Laboratory

FERMILAB-Pub-76/28-EXP
7200.194

(Submitted to Phys. Rev. Lett.)

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March 1976

Operated by Universities Research Association Inc. under contract with the Energy Research and Development Administration

FERMILAB-Pub-76/28-EXP
SUNY-SB BCG-76-06

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ABSTRACT

We have measured the inclusive cross section for the reactions $pn \rightarrow pX$ and $\pi^{+}n \rightarrow pX$ at 100 GeV/c in the kinematic region $|t| < 1.0$ GeV^{2}. The data were obtained from an exposure of the Fermilab 30-inch deuterium-filled bubble chamber to a tagged positively charged beam. The differential cross sections for these reactions are observed to scale in the ratio of the pn and $\pi^{+}n$ total cross sections and to be consistent with the predictions of a Reggeized one pion exchange model. We use this model to extract values of the $\pi^{-}\pi^{+}$ total cross section from the $\pi^{+}n \rightarrow pX$ data. The results agree with the factorization prediction.

†Research supported by the National Science Foundation.

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We present a study of the reactions

$$p + n \rightarrow p + X \quad (1)$$

and

$$\pi^{+} + n \rightarrow p + X \quad (2)$$

from an analysis of 41000 pictures of interactions in the Fermilab 30-inch deuterium-filled bubble chamber exposed to an unseparated beam of 100 GeV/c positive particles. A tagging system[1] allowed the identification of individual beam particles from their position in the bubble chamber. The film was scanned twice, with an efficiency of (99±1)%, for interactions with three or more outgoing charged particles. The tracks of the slow secondary particles (projected laboratory momenta $\lesssim$ 1.5 GeV/c) were measured and reconstructed in space, and protons with momentum less than 1.2 GeV/c were identified by their ionization in the bubble chamber. Inelastic one and two prong events with all visible particles slow in the laboratory were identified in a separate scan of 10000 frames and processed as above. We assume the impulse approximation[2] to be valid, and identify neutron target events by the presence of a spectator proton with momentum less than 300 MeV/c.

We have previously argued that the invisible spectator proton events, which comprise about 2/3 of our data on reactions(1) and (2), may be interpreted as an unbiased sample of neutron target interactions[3]. Accordingly, we calculate the cross section for reactions (1) and (2) from the invisible spectator sample by normalizing the total number of invisible spectator events[4] to the inelastic cross section for pn[5] and $\pi^{+}n$[6] collisions, respectively. This method of normalization obviates the need to correct the data for Glauber screening and rescattering. We obtain a cross section of (5.7 ± 0.3) mb for reaction (1) and (3.9 ± 0.3) mb for reaction (2), for $|t| < 1.0$ GeV^2, where t is the four-momentum transfer squared from the neutron target to the slow proton. Our data constitute a 115 event/mb sample of reaction (1) and an 82 event/mb sample of reaction (2). The fraction of the total pn cross section which contributes to reaction (1) is $0.15 \pm .01$, while $0.16 \pm .01$ of the π^+n total cross section contributes to reaction (2), for $|t| < 1.0$ GeV^2. The equality of these two fractions suggests that the fractional cross section for slow proton production from a neutron target is independent of the incident beam particle.

We display in Fig. 1(a) the distribution of missing mass squared (M^2) recoiling against the slow proton, or equivalently the mass squared of the system X, from reactions (1) and (2) for $|t| < 1.0$ GeV^2. The uncertainty in the target momentum of the invisible spectator events leads to a resolution (FWHM) of 13 GeV^2 (a value large compared with the resolution resulting from measurement errors) independent of M^2, and is responsible for the negative M^2 data. The low M^2 peak attributed to diffractive fragmentation of the beam proton in the inelastic reaction[7] $pp \rightarrow pX$ is observed to be absent from the neutron target data.

We compare the inclusive M^2 distributions from reactions (1) and (2) in Fig. 1(b), where we plot the ratio

$$R = \frac{d\sigma/dM^2(\pi^+n \rightarrow pX)}{d\sigma/dM^2(pn \rightarrow pX)} \qquad (3)$$

as a function of M^2. The dashed line indicates the average value of this ratio. The ratio (3) is consistent with being independent of M^2 and equal to the ratio of the total π^+n and pn cross sections, suggesting that the same mechanism is responsible for slow proton production in reactions (1) and (2).

The isospin one exchange particles which could mediate reactions (1) and (2) are the π, ρ, and A_2. Bishari[8] and Field and Fox[9] have suggested that the dominant mechanism in high energy charge exchange reactions may be pion exchange. By extrapolation to the pion mass shell, Bishari parameterizes the pion exchange contribution to the differential cross section for reaction (1) as

$$s \frac{d\sigma(pn\to pX)}{dt\, dM^2} = \frac{1}{4\pi} \frac{g^2_{\pi np}}{4\pi} \frac{-t}{(t-m^2_\pi)^2} \left(\frac{s}{M^2} \right)^{2\alpha_\pi(t)-\alpha_P(0)} \tag{4}$$

$$\times\ \sigma_T(\pi^- p)\ \exp[b(t-m_\pi{}^2)],$$

where $g^2_{\pi np}/4\pi = 2\, g^2_{\pi pp}/4\pi \gtrsim 29.0$ is the on-mass-shell coupling, $\sigma_T(\pi^- p)$ is the total $\pi^- p$ cross section at c.m. energy $\sqrt{s} = M$, and b is a parameter to account for possible off-mass-shell corrections. The pion Regge trajectory function is $\alpha_\pi(t) = t, \alpha_P(0) = 1$, and m_π is the pion mass. Eq. (4) is derived for s/M^2 and M^2 large, and $|t|$ small. In the triple-Regge formalism Eq. (4) is the sum of the contributions of the $\pi\pi P$ and $\pi\pi R$ terms. Field and Fox include these terms in an analysis of the reaction $pp \to pX$ where they fit the various triple-Regge couplings. Their solutions favor $b \gtrsim 0$. Accordingly, we compare reaction (1) with the prediction of Eq. (4) with $b = 0$, and use a parameterization of $\pi^- p$ data[10] for $\sigma_T(\pi^- p)$.

We display in Fig. 2 values of $s\, d\sigma/dtdM^2$ from reaction (1) as functions of M^2 averaged over the three indicated t intervals. The curves are the predictions of Eq. (4), which we have modified to include the effects of the invisible spectator events[11]. We observe substantial agreement with the predictions of the Reggeized pion exchange model. The data do not discriminate against a model incorporating ρ/A_2 exchange if b in Eq. (4) is allowed to be non-zero. However, we find it remarkable that the pion exchange model is sufficient to describe the data over the full range of t and M^2 values accessible in this experiment.

Reaction (1) has been previously studied[12] with data from the deuterium gas jet target at Fermilab in the restricted kinematic region $0.14 < |t| < 0.38$ GeV^2 and $0.07 < M^2/s < 0.20$, and was observed to be compatible with the prediction of Eq. (4) with b = 0. Our data on reaction (1) are consistent with those of Ref. 12 in the region of overlapping t and M^2/s. In a recent ISR experiment[13] the reaction $pp \to nX$ was investigated over a wide range of t and M^2/s values. We expect the invariant cross sections for the reactions $pn \to pX$ and $pp \to nX$ to be equal in the target fragmentation region if the reactions are isospin invariant and independent of the incident beam particle. However, our values of $s\, d\sigma/dtdM^2$ for reaction (1) are a factor of 2-4 larger than those reported in the ISR experiment at the same values of t and M^2/s.

In view of the previously noted similarities between reactions (1) and (2), we expect reaction (2) to also be described by the pion exchange model. The pion exchange contribution to the differential cross section for reaction (2) is parameterized by replacing $\sigma_T(\pi^- p)$ in Eq. (4) with the total $\pi^-\pi^+$ cross section. Since there are no directly measured values of the $\pi^-\pi^+$ cross section, we solve for $\sigma_T(\pi^-\pi^+)$:

$$\sigma_T(\pi^-\pi^+) = s\,\frac{d\sigma(\pi^+ n\to pX)}{dt\;dM^2} \bigg/ \frac{1}{4\pi}\,\frac{g^2_{\pi np}}{4\pi}\;\frac{-t}{(t-m_\pi^2)^2}\left(\frac{s}{M^2}\right)^{2t-1} \qquad (5)$$

Thus, if reaction (2) is dominated by pion exchange, we may deduce the total $\pi^-\pi^+$ cross section at $s = M^2$ from our data. If ρ/A_2 exchange plays an important role in reaction 2, however, Eq. (5) should be interpreted as an average Reggeon-pion total cross section.

We plot the quantity given by Eq. (5) in Fig. 3, averaged over the same t intervals as in Fig. 2, and compare the data with the factorization prediction[14]

$$\sigma_T(\pi^-\pi^+) = \sigma_T(\pi^-p)\sigma_T(\pi^+p) \;/\; \sigma_T(pp). \qquad (6)$$

The curve in Fig. 3 is calculated from parameterizations of the three measured total cross sections[10,15] in Eq. (6). We observe the factorization prediction to be consistent with the cross sections derived from our data. We include in Fig. 3 low energy values of $\sigma_T(\pi^-\pi^+)$ from an analysis of 25 GeV/c π^-p data[16]. The $\pi^-\pi^+$ total cross section is observed to fall rapidly from the resonance region to an asymptotic value of about 14-16 mb.

In conclusion, we have found the cross sections for the reactions $pn \rightarrow pX$ and $\pi^+n \rightarrow pX$ to be in the ratio of the pn and π^+n total cross sections in the kinematic region $|t| < 1.0$ GeV^2 and $M^2 < 100$ GeV^2. The reaction $pn \rightarrow pX$ is satisfactorily described by a Reggeized one pion exchange model, and values of $\sigma_T(\pi^-\pi^+)$ calculated with this model from the $\pi^+n \rightarrow pX$ data are consistent with the predictions of factorization.

We thank the staffs of the Neutrino Laboratory and 30-inch Bubble Chamber at Fermilab for their help and cooperation, and gratefully acknowledge the assistance of the Proportional Hybrid System Consortium. We thank R.D. Field, P. Hoyer and J.M. Wang for valuable discussions, and express our appreciation to our scanning and measuring staffs who helped extract these data from the film.

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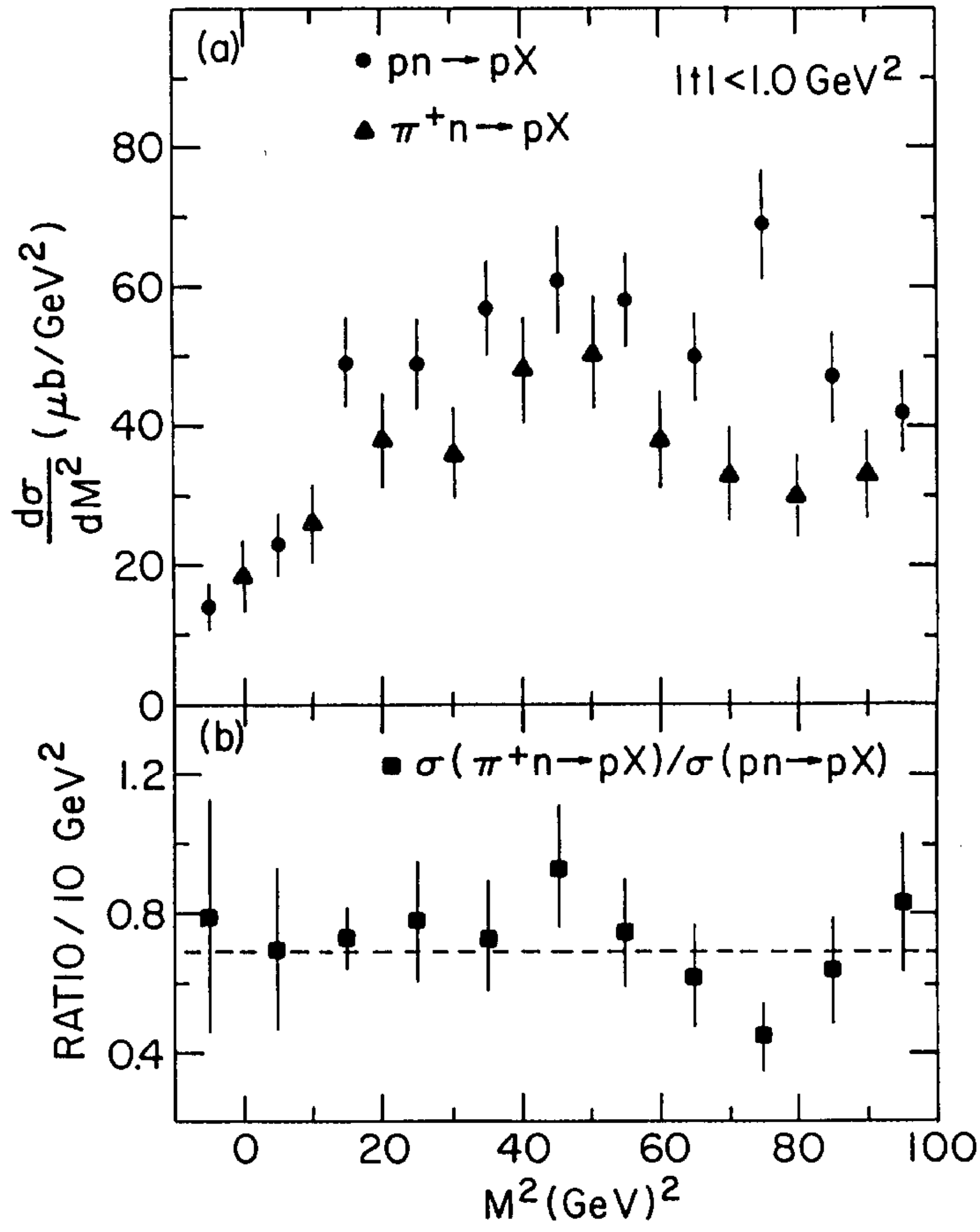

Fig. 1. (a) Distributions of the invariant mass squared of the system X in the reactions $pn \to pX$ and $\pi^+n \to pX$ for $|t| < 1.0$ GeV^2. (b) Ratio of the distributions $[d\sigma/dM^2(\pi^+n\to pX)]/[d\sigma/dM^2(pn\to pX)]$ as a function of M^2. The dashed line is the average value of this ratio.

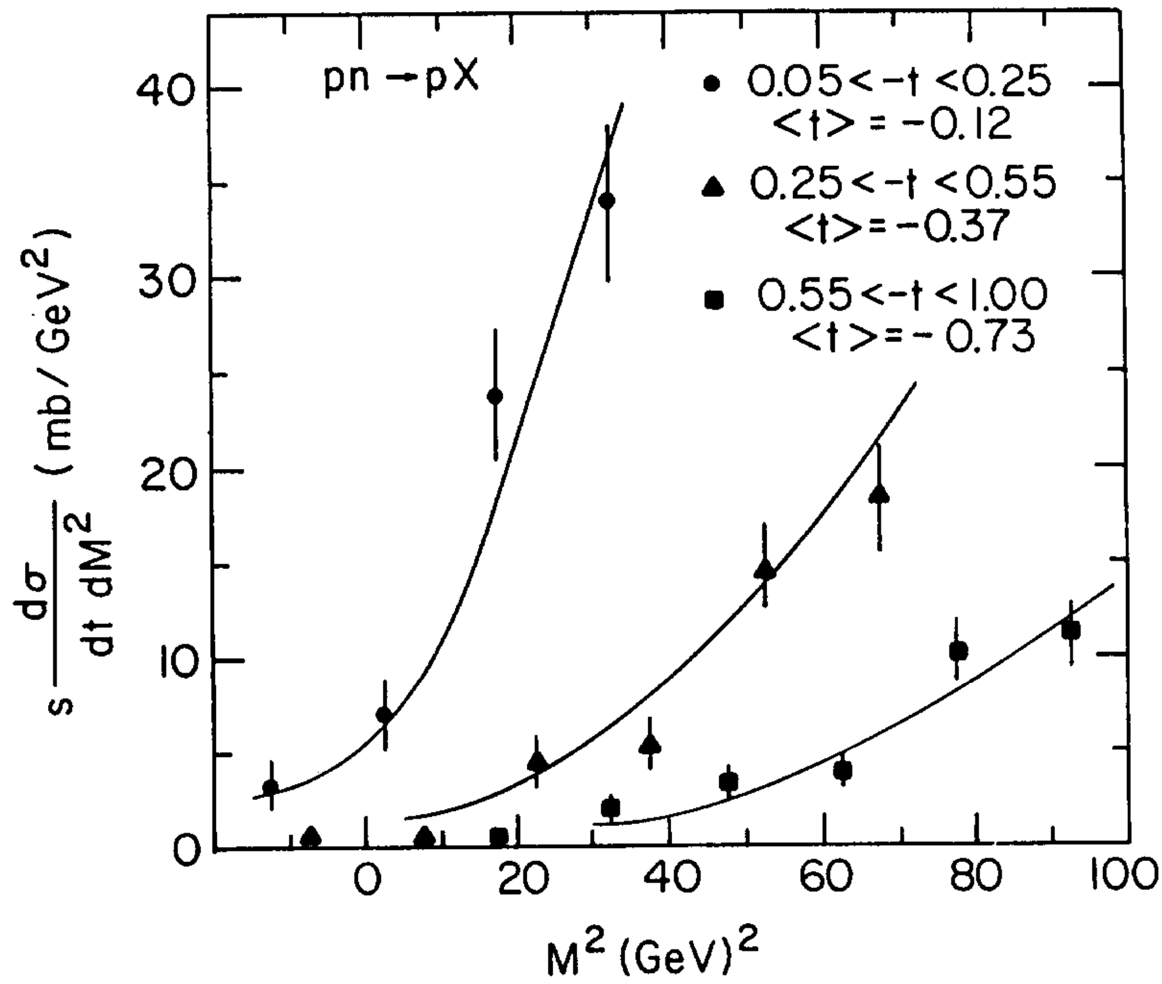

Fig. 2. Invariant cross section for the reaction pn → pX as a function of M^2 averaged over the indicated t intervals. The units of t are GeV^2. The curves are the predictions of Eq. (4).

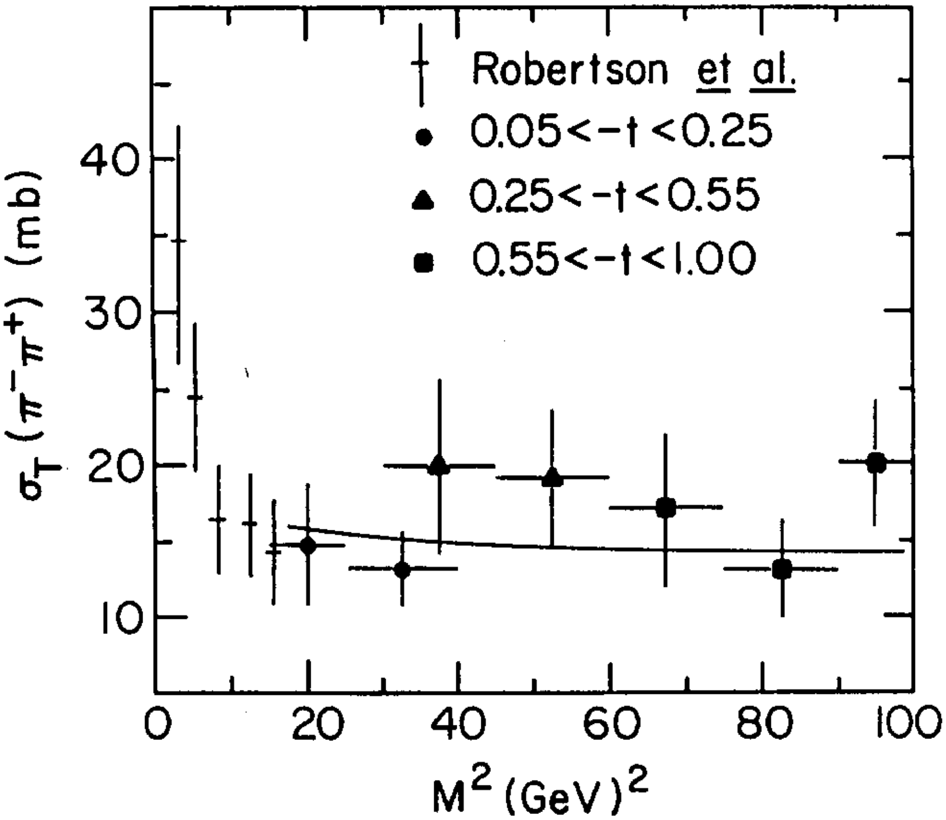

Fig. 3. $\sigma_T(\pi^-\pi^+)$ computed with Eq. (5) from the $\pi^+n \to pX$ data as a function of $s = M^2$. The curve is the factorization prediction of $\sigma_T(\pi^-\pi^+)$. The low M^2 data points are from Ref. 16.