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ABSTRACT

We present high-statistics results on the reactions $a + p \rightarrow c + X$ where a and c can be any of $\pi^{\pm}$, $K^{\pm}$, p, or $\bar{p}$. The data were taken at 100 and 175 GeV/c incident momenta using the Fermilab Single Arm Spectrometer operated over the kinematic range $0.2 < x < 1.0$ and $p_t \leq 1.0$ GeV/c. Investigating the x-dependence of the data, we find agreement with a quark-parton picture, namely the cross sections have a power law behavior in (1-x) independent of p_{beam} and p_t.

We have performed a high energy inclusive scattering experiment to study the process $a + p \rightarrow c + X$, where a and c can be any of $\pi^{\pm}$, $K^{\pm}$, p or $\bar{p}$. The production of particle c was measured over the Feynman x range, $0.2 \leq x \leq 1.0$, and the transverse momentum range, $0.3 \leq p_t \leq 1.0$ GeV/c. Data were taken using the Fermilab M6E beam line and the Single Arm Spectrometer (SAS) facility with incident beam momenta of 100 and 175 GeV/c.

It has recently been suggested that the basic hadron constituents may reveal themselves in low p_t, soft hadronic processes as well as in leptoproduction and large p_t scattering.[1] Several models have elaborated upon this idea, yielding predictions for the x dependence of the hadronic fragments based on the quark-parton distributions derived from leptoproduction data.[2] A model proposed by Brodsky and Gunion[3] yields the simple prediction for all reaction channels that the hadronic fragments will be distributed according to $(1-x)^n$ in the region, $0.2 \leq x \leq 0.8$, and that the exponents will be independent of p_t. Since many reaction channels were studied, this experiment is well suited for testing these predictions.[4]

Data were taken for more than 300 different beam/spectrometer momentum settings, and at each kinematic point nine reaction rates ($\pi \rightarrow \pi$, $\pi \rightarrow K$, etc.) were measured simultaneously. Both the beam line and the spectrometer were instrumented with four

Cerenkov counters, giving good π/K/p separation over the complete kinematic range of experiment. The beam was incident on a 50 cm. liquid hydrogen target after passing through a series of pitching magnets. These were used to vary the angle of incidence, and hence the scattering angle. The spectrometer, which was 150 m. long and had a maximum acceptance of 32 μsr-%, has been described elsewhere.[5]

The raw data were corrected for several effects in the determination of the cross sections.[4,6] The most important correction resulted from the combined effects of particle absorption and decay in the spectrometer. These effects were measured to ± 2% with special runs in which an incident beam of reduced energy was run directly through the spectrometer. The transmitted fraction was lowest for kaons, and varied from 50% at 30 GeV/c to 85% at 100 GeV/c. At the same momenta, the transmitted fractions were 78% and 93% respectively, for both pions and protons. For spectrometer settings below 40 GeV/c it was also necessary to correct for multiple scattering losses; this correction was 6% at 30 GeV/c. Particle misidentification occurred at a negligible level, with the exception of a 5% correction for kaons decaying in the spectrometer and being tagged as pions. Finally, a 2% correction was made for track reconstruction inefficiencies.

For each data point, systematic errors due to geometrical asymmetries were minimized by averaging runs with the beam pitched up and down at the same angle through the target.

Empty target rates were typically 25% of the full target rates at small scattering angles, dropping to 5% at larger angles. The relative systematic error between reaction channels is estimated to be less than 5%; the overall normalization is known to better than 15%. The error bars in the data plots are statistical only. It should be noted that the results of the fits presented below are insensitive to possible uncertainties in the normalization of the data.

Figure 1 gives an example of the quality of the data obtained in this experiment. It shows the x dependence of the invariant cross sections for $\pi^+ p \rightarrow c^\pm X$ at $p_t = 0.3$ GeV/c and $p_{beam} = 100$ GeV/c. With the exception of the leading $\pi^+ \rightarrow \pi^+$ channel, the data all fall with increasing x, some channels doing so quite precipitously. The solid curves are fits to the $(1-x)^n$ parameterization and are in good agreement with the data. As reported previously[7], the enhancement at large x in the $\pi^+ \rightarrow \pi^-$ data is a reflection of forward ρ and f production, where the π^- is a secondary decay product. Because of this effect, an estimate of which is given by the dashed curve in Fig. 1, the $\pi^\pm \rightarrow \pi^\mp$ data with $x > 0.5$ have been eliminated from the power law fits. Similarly, the excess of events for $x \geq 0.8$ in the $\pi^+ \rightarrow K^+$ channel can be explained by a triple Regge diagram with K^* exchange[6,8] (dotted curve in Fig. 1). In order to minimize such difficulties at high x, the power law fits for all reaction channels have been limited to $x \leq 0.7$.

The x dependence of the $\pi^+ \to K^-$ reaction is displayed on a logarithmic scale in Fig. 2 for several values of p_t at two different incident momenta. The data have been normalized so that the power law fits, which are straight lines in this plot, coincide at x = 1. It is apparent that the power law exponents are independent of p_{beam} and p_t for this channel. This behavior is also found for the other non-leading reaction channels. Therefore, all the data for a given channel with $x \leq 0.7$ have been fit using the parametrization

$$E \frac{d^3\sigma}{dp^3} = f(p_{beam}, p_t) \cdot (1-x)^n \qquad (1)$$

where n is independent of p_{beam} and p_t. As shown by the curves in Figs. 1 and 2, this parametrization fits the data well. The resulting exponents are plotted and tabulated in Fig. 3. The largest exponents are obtained for those channels with the greatest difference between incoming and outgoing quantum numbers.

Brodsky and Gunion give a simple prescription for computing the power law exponents[3], namely $n = 2n_s - 1$, where n_s is the number of spectator quarks in the process $a \to c$. (Strictly speaking, their prediction gives lower limits for the different n.) As an example, Fig. 4 shows the quark line diagram for the process $\pi^+ \to K^+$. As seen from the figure, there are two possible values for n_s, depending on the production mechanism involved. If the mechanism is quark exchange or annihilation, the value of n_s is one unit less than when the exchange of a gluon mediates the interaction. Since 1-x is proportional to the energy which remains available for the spectators after particle a is transformed into particle c, then $(1-x)^{2n_s-1}$ is proportional to the available phase space for the spectators. For a large number of spectator quarks, e.g., $p \to \bar{p}$, the cross section must, therefore, be strongly suppressed for $x \to 1$. The Brodsky and Gunion predictions for both quark and gluon exchange for the various reaction channels are included in Figure 3.

It is clear that the (1-x) powers measured in our experiment fall into hierarchies which roughly follow the quark exchange/annihilation predictions, but are in clear disagreement with the minimum values predicted for gluon exchange. However, all the meson → meson channels with double charge exchange have exponents more than two units less than the quark exchange prediction, n = 5. It is in these channels that the data at high x are enhanced by the production and decay of meson resonances. The data with incident protons agree well with the results of Johnson et al.,[9] (x points in Fig. 3). Similar power law behavior has also been seen in various channels by other experiments. The experimental evidence, therefore, suggests that the underlying constituents of hadrons are important in describing fragmentation processes at low p_t, and that quark exchange/annihilation is the dominant mechanism for these processes.

We would like to express our thanks to the many people at Fermilab who have contributed to the successful operation of the Single Arm Spectrometer and of the accelerator. This work was supported in part by the U. S. Department of Energy under Contract Numbers EY76-C-02-3000 (Fermilab), 3069 (MIT), 3130 (Brown), and the Istituto Nazionale de Fisica Nucleare (Italy).

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FIGURES

Figure 1. Invariant cross sections for all channels of the type $\pi^+ p \rightarrow c^{\pm} X$ at $p_{beam} = 100$ GeV/c and $p_t = 0.3$ GeV/c. The solid curves are power law fits to equation (1). The dashed curve includes ρ and f resonance contributions from reference 7. The dotted curve is a triple Regge representation in the high x region from reference 6.

Figure 2. Invariant cross sections for the channel $\pi^+ p \rightarrow K^- X$ normalized by the fitted coefficients $f(p_{beam}, p_t)$ of equation (1). The straight line is the function $(1-x)^n$ where the fitted value of n is 2.3 ± 0.2.

Figure 3. Fitted exponents from equation (1) for the observed channels. Exponents from reference 9, obtained in pp collisions, are given (x symbols) for comparison. The solid (dashed) lines are the minimum values predicted for quark (gluon) exchange.

Figure 4. Quark line diagram for the fragmentation of π^+ into K^+ illustrating the quark exchange or annihilation and gluon exchange processes.

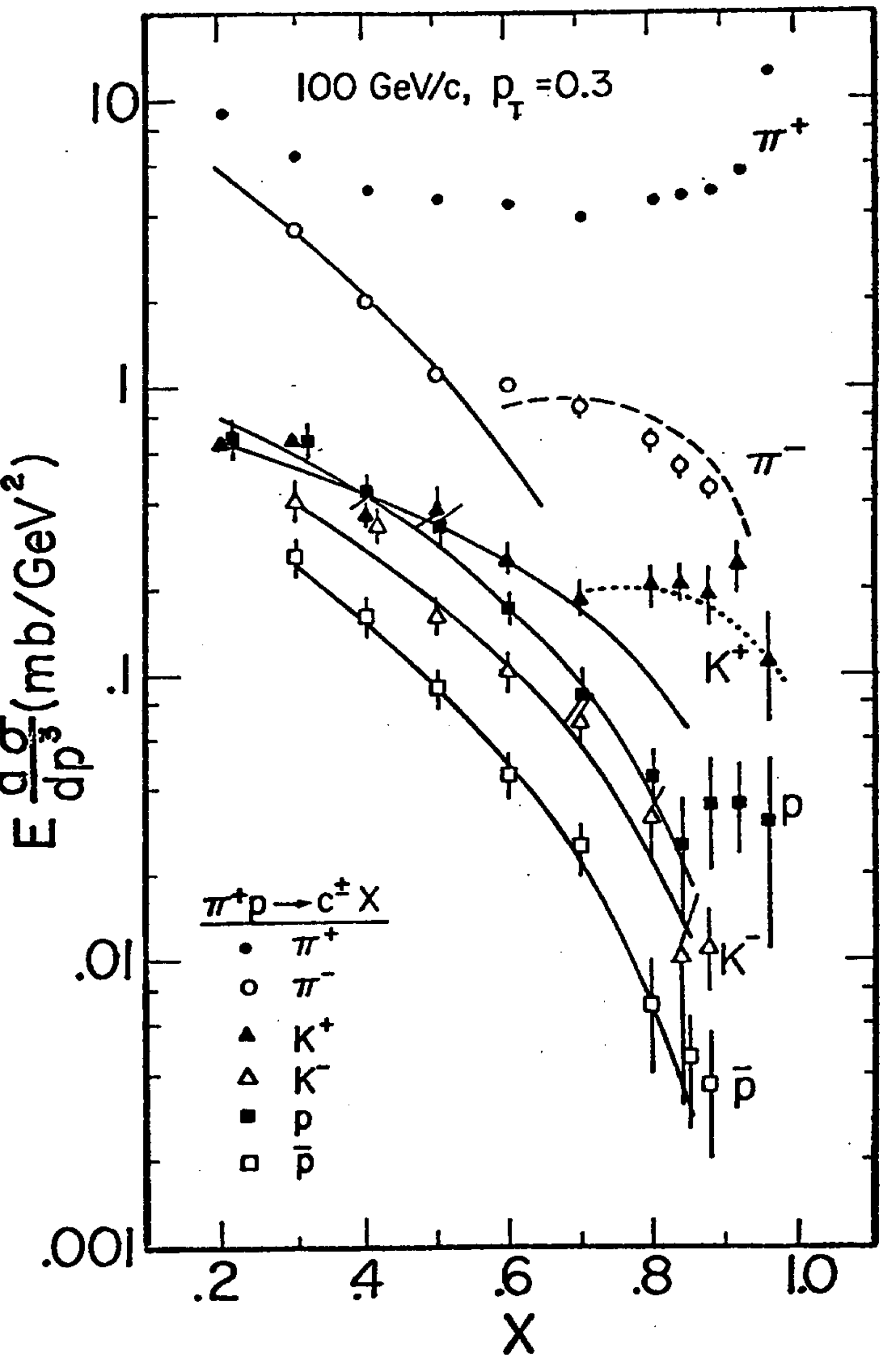
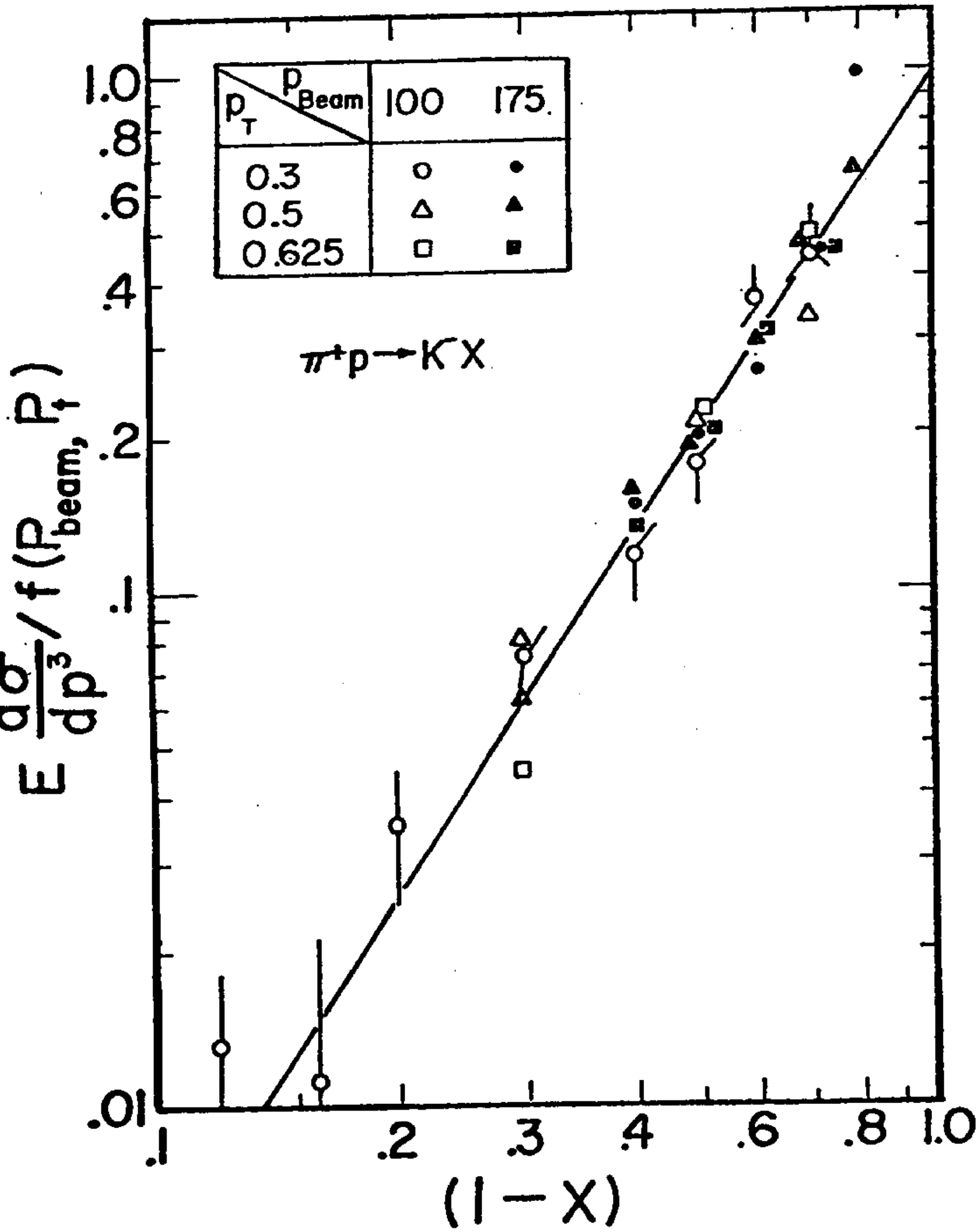

100 GeV/c, p_T =0.3
10
1
.1
.01
.001
.2
.4
.6
.8
1.0
X
$E\frac{d^3\sigma}{dp^3}$(mb/GeV^2)
π^+
π^-
K^+
p
K^-
$\bar{p}$
$\pi^+ p \to c^\pm X$
π^+
π^-
K^+
K^-
p
$\bar{p}$

FIG. 1



p_T
p_{Beam}
100
175
0.3
0.5
0.625
$\pi^+ p \to K^- X$
$E \frac{d^3\sigma}{dp^3} / f(P_{beam}, P_t)$
1.0
.8
.6
.4
.2
.1
.01
.1
.2
.3
.4
.6
.8
1.0
(1 − X)

FIG. 2

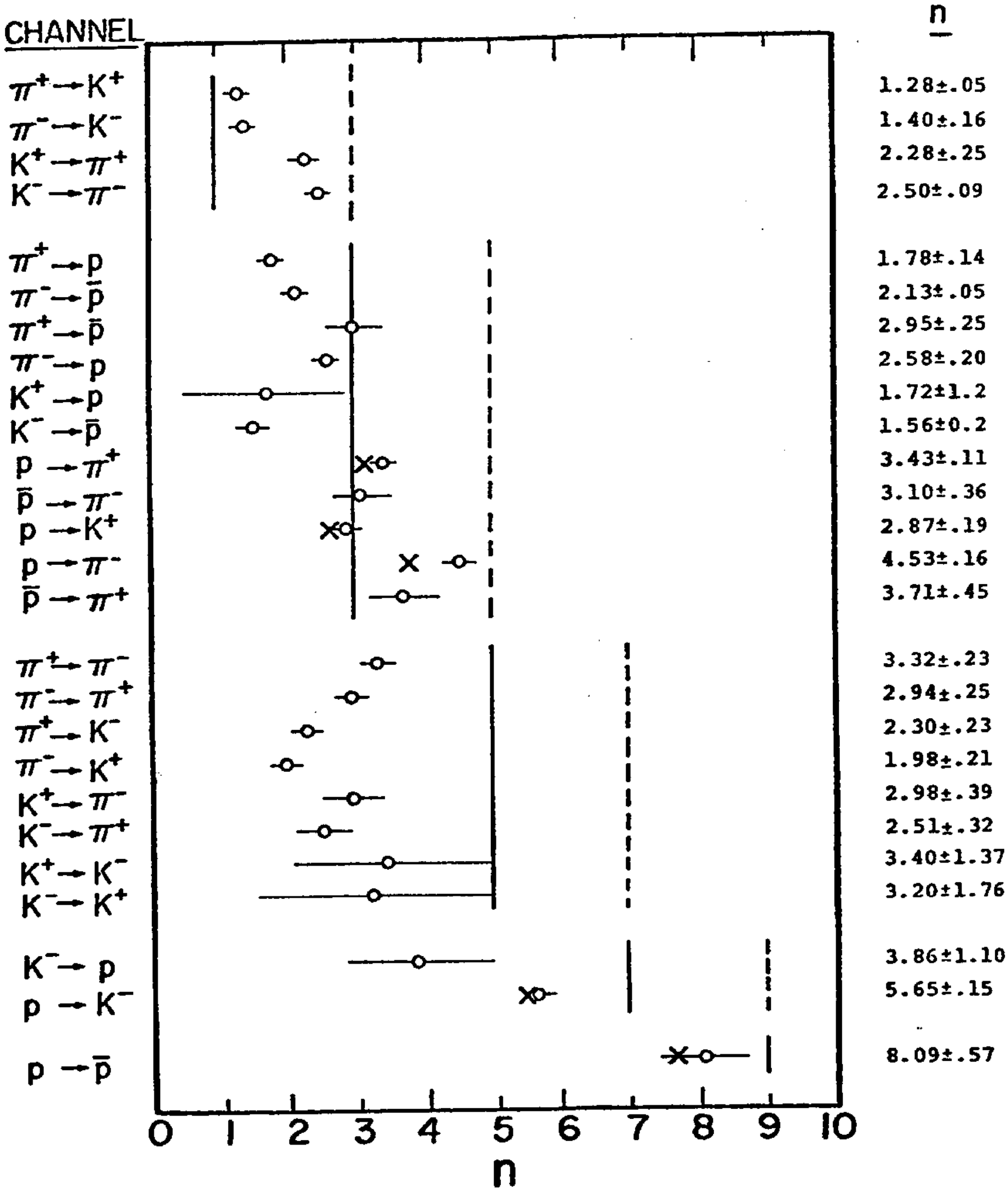

CHANNEL
n
π⁺ → K⁺ 1.28±.05
π⁻ → K⁻ 1.40±.16
K⁺ → π⁺ 2.28±.25
K⁻ → π⁻ 2.50±.09
π⁺ → p 1.78±.14
π⁻ → p̄ 2.13±.05
π⁺ → p̄ 2.95±.25
π⁻ → p 2.58±.20
K⁺ → p 1.72±1.2
K⁻ → p̄ 1.56±0.2
p → π⁺ 3.43±.11
p̄ → π⁻ 3.10±.36
p → K⁺ 2.87±.19
p → π⁻ 4.53±.16
p̄ → π⁺ 3.71±.45
π⁺ → π⁻ 3.32±.23
π⁻ → π⁺ 2.94±.25
π⁺ → K⁻ 2.30±.23
π⁻ → K⁺ 1.98±.21
K⁺ → π⁻ 2.98±.39
K⁻ → π⁺ 2.51±.32
K⁺ → K⁻ 3.40±1.37
K⁻ → K⁺ 3.20±1.76
K⁻ → p 3.86±1.10
p → K⁻ 5.65±.15
p → p̄ 8.09±.57
0 1 2 3 4 5 6 7 8 9 10
n

Fig. 3

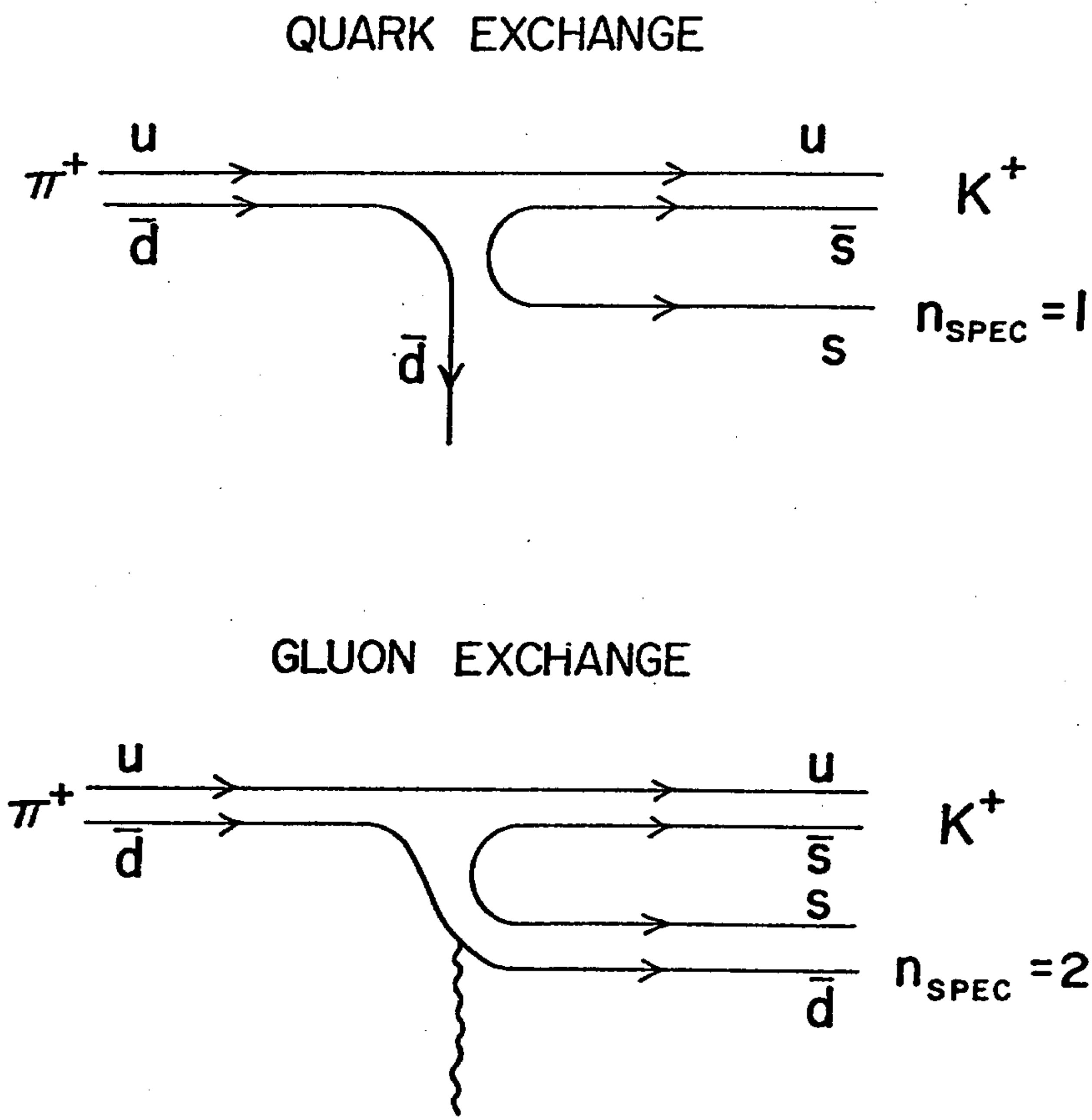

QUARK EXCHANGE
π+
u
d̄
d̄
u
s̄
s
K+
nSPEC =1
GLUON EXCHANGE
π+
u
d̄
u
s̄
s
d̄
K+
nSPEC =2

FIG. 4