Experimental Study of Low-\(p_t\) Hadron Fragmentation

D. Cutts, R. S. Dulude, R. E. Lanou, Jr., and J. T. Massimo

*Brown University, Providence, Rhode Island 02912*

and

R. Meunier

*CERN, Geneva, Switzerland*

and

A. E. Brenner, D. C. Carey, J. E. Elias, P. H. Garbincius, G. Mikenberg, and V. A. Polychronakos

*Fermi National Accelerator Laboratory, Batavia, Illinois 60510*

and

M. D. Chiaratia, C. DeMarzo, C. Favuzzi, G. Germinario, L. Guerriero, P. LaVopa, G. Maggi, F. Posa, G. Selvaggi, P. Spinelli, and F. Waldner

*Istituto di Fisica and Istituto Nazionale di Fisica Nucleare, Bari, Italy*

and


*Massachusetts Institute of Technology, Cambridge, Massachusetts 02139*

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We present high-statistics results on the reactions \(a + p \rightarrow c + X\) where \(a\) and \(c\) can be any of \(\pi^+, K^+, p, \) 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 \(p_t < 1.0\) 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 \(\pi^+, K^+, p, \) or \(\bar{p}\). The production of particle \(c\) was measured over the Feynman \(x\) range \(0.2 < x < 1.0\), and the transverse momentum range \(0.3 < p_t < 1.0\) 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. This is the first high-energy, high-resolution study of beam fragmentation for incident particles other than protons with good Cherenkov identification.

It has recently been suggested that the basic hadron constituents may reveal themselves in low-\(p_t\), soft hadronic processes as well as in lepto-production and large-\(p_t\) scattering. 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. A model proposed by Brodsky and Gunion yields the simple prediction for all reaction channels that the hadronic fragments will be distributed according to $(1-x)^n$ in the region $0.2 < x < 0.8$, 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.

Data were taken for more than 300 different beam and spectrometer momentum settings, and at each kinematic point nine reaction rates ($\pi^-\pi^-$, $\pi^-K$, etc.) were measured simultaneously. Both the beam line and the spectrometer were instrumented with four Cherenkov counters, giving good $\pi^-K^-\rho$ 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 $\mu$sr $^\circ$, has been described elsewhere.

The raw data were corrected for several effects in the determination of the cross sections. The most important correction resulted from the combined effects of particle absorption and decay in the spectrometer. These effects were measured to $\pm 2\%$ 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 datum 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 be better than $15\%$. The error bars in the data plots are statistical only. However, in the power-law fits an additional $10\%$ error has been added in quadrature to account for possible point-to-point systematic uncertainties.

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 $\pi^-\rho^{-}\rightarrow c^+X$ at $p_{\text{beam}}=100$ GeV/c and $p_t=0.3$ GeV/c. With the exception of the leading $\pi^-\pi^+$ channel, the data all fall with increasing $x$, some channels doing so quite precipitously. The solid curves are fits by the $(1-x)^n$ parametrization and are in good agreement with the data. As reported previously, the enhancement at large $x$ in the $\pi^-\pi^+$ data is a reflection of forward $\rho$ and $f$ production, where the $\pi^+$ is a secondary decay product. Because of this effect, an estimate of which is given by the dashed curve in Fig. 1, the $\pi^-\pi^+$ data with $x>0.5$ have been eliminated from the power-law fits. Similarly, the excess of events for $x>0.8$ in the $\pi^-K^+$ channel can be explained by a triple-Regge diagram with $K^*$ exchange (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 $x \leq 0.7$. Using a lower $x$ limit reduces the statistics but does not alter the results.

The $x$ dependence of the $\pi^+K^-$ 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 nonleading reaction channels. Therefore, all the data for a given channel with $x \leq 0.7$ have been fitted using the parametrization

$$E^{3\alpha} / dp^3 = f(p_{beam}, p_t)(1-x)^n,$$

where $n$ is independent of $p_{beam}$ and $p_t$ and a different coefficient $f(p_{beam}, p_t)$ is used for each $x$ sweep. 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 Guion give a simple prescription for computing the power-law exponents, namely, $n = 2n_s - 1$, where $n_s$ is the number of spectator quarks in the process $a \rightarrow c$. (Strictly speaking, their prediction gives lower limits for the different $n_s$.) As an example, Fig. 4 shows the quark-line diagram for the process $\pi^+K^-$. 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 $(1-x)^{n_s-1}$ is proportional to the available phase space for the spectators. For a large number of spectator quarks, e.g., $p → p$, the cross section must, therefore, be strongly suppressed for $x \rightarrow 1$. The Brodsky and Guion predictions for both quark and gluon exchange for the various reaction channels are included in Fig. 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.
annihilation is the dominant mechanism for these processes.

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(6) Present address: DESY, Hamburg, West Germany.
(7) Present address: Brookhaven National Laboratory, Upton, N. Y. 11793.
(8) Present address: Centre d'Études Nucléaires de Saclay, Gif-sur-Yvette, France.
(9) Present address: Bell Laboratories, Holmdel, N. J. 07733.