Inclusive Hadron Exchange Scattering at 50-175 GeV*

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Measurements of inclusive hadron processes of the type $a+p\to b+\cdots$ have been made at energies of 50 to 175 GeV for Feynman x in the range 0.75 to 0.95 and $-t$'s up to 0.65 GeV^2. The invariant cross sections are satisfactorily parametrized by a simple form derived from Regge theory.

We have used the Fermilab Single-Arm Spectrometer Facility to measure the inclusive reactions

$$\pi^+ + p \to K^+ + \ldots , \quad (1a)$$

$$\pi^- + p \to K^- + \ldots , \quad (1b)$$

$$\pi^- + p \to \bar{p} + \ldots , \quad (1c)$$

$$\pi^+ + p \to p + \ldots , \quad (1d)$$

$$p + p \to \pi^+ + \ldots , \quad (1e)$$

$$p + p \to K^+ + \ldots . \quad (1f)$$

In the context of Regge theory, inclusive reactions of the type $a+p\to b+\ldots$ are of particular interest as they inovlve quantum-number exchange and cannot proceed via Pomeron exchange. Extensive measurements exist for inclusive reactions of the type $a+p\to a+\ldots$, which at large x values are dominated by Pomeron exchange, but relatively few measurements exist for inclusive reactions not involving Pomeron exchange.[1]

The experiment was performed with the Fermilab Single Arm Spectrometer Facility.[2] Particle type was determined in both the beam line and spectrometer allowing all inelastic processes with particles of given charge to be measured at the same time. Incoming beam particles were tagged for particle type by a threshold Cherenkov counter (pions), a counter[3] (kaons or protons), and a differential Cherenkov counter (protons or kaons). A magnetic deflection system varied the angle of the beam at the liquid hydrogen target. Outgoing particles scattered into the spectrometer were identified with a differential counter set for protons (the counter also contained an anti ring efficient for kaons and pions), a long threshold counter set to count pions, and two shorter threshold counters set to count kaons and pions at lower energies.

The experiment was run with beam intensities of (2 to 3)$\times 10^6$ particles per burst and with ~10% of the rf buckets occupied by two particles. To avoid random events, the major source of background, the trigger requirement for reactions of the type $a+p\to b+\ldots$ was set to be a present and b *not* present in the beam and b present in the spectrometer. Therefore the Cherenkov counters in the beam required both high rejections against unwanted particle types and high detection efficiencies. At incident energies above 100 GeV the efficiency of the threshold counter for pions dropped. However, the anti ring of the differential counter counted pions or kaons with 99.8% efficiency and was used in anticoincidence to ensure that protons in the beam line were unaccompanied by pions and kaons. The differential counter retained 99.8% or better efficiency for proton detection up to the highest energies. An additional rejection factor of about 10 against the background was obtained by requiring only one particle in the beam-line hodoscopes. With these strict Cherenkov and hodoscope requirements, the background from randoms was reduced to less than 5% of the signal for $x \leq 0.95$. The combined rejection ratios were measured by observing the fraction of incorrectly identified events

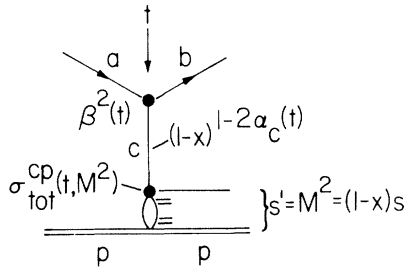

FIG. 1. Diagrammatic representation of an inclusive process of the type $a+p\to b+\cdots$ via Regge exchange of a particle c.

which satisfied the kinematics of elastic scattering.

Inclusive exchange processes have small cross sections and therefore fiducial cuts on the acceptance were kept wide to obtain maximum counting rates. Data[4] for the high-rate processes $\pi^{\pm}+p\to\pi^{\pm}+\ldots$ were taken in parallel with the inclusive exchange measurements and were used to calibrate the spectrometer acceptance.

The systematic uncertainties introduced by the calibration of acceptances and efficiencies were about 10%. The total number of recorded events was about 4000 events each for $\pi^-\to K^-$ [Reactions (1a) and (1b)], about 1000 events for $\pi^-\to p$ [Reactions (1c), (1d), and (1e)], and about 300 events for $p\to K^+$.

Regge theory parametrizes cross sections for inclusive processes[1,5] of the type $a+p\to b+M_M^2$ (see Fig. 1) with the form

$$\frac{d^2\sigma}{dt\,dx}=\sum_i\frac{|\beta_{abc_i}(t)|^2}{16\pi s_0^{\,2}}\times(1-x)^{1-2\alpha_i^{\,c}}\sigma_{tot}^{c_i p}(t,M_M^{\,2}),\quad(1)$$

where $\beta_{abc_i}(t)$ is the residue function for an exchanged Reggeon c_i; $\alpha_i^{\,c}$ is the corresponding Regge trajectory; and $\sigma_{tot}^{c_i p}(t,M_M^{\,2})$ is the effective total cross section for Reggeon c_i on a proton at a subenergy corresponding to the square of the missing mass ($M_M^{\,2}$). To limit the number of parameters, the data were fitted to a semiempirical form suggested by Eq. (1):

$$\frac{d^2\sigma}{dt\,dx}=\frac{|\beta|^2(1-x)^{(1-2\alpha_{\rm eff})}}{16\pi s_0^{\,2}}\times e^{b_{\rm eff}t}\,\sigma_{tot}^{cp}(M_M^{\,2}),\quad(2)$$

where the measured total cross sections for πp, Kp, and pp, depending on the strangeness and baryon quantum numbers being exchanged, were used as an approximation for $\sigma_{tot}^{cp}(M_M^{\,2})$. The additional approximations involved in this equation are the following: In principle the $\alpha_i^{\,c}$ and σ_{tot}^{cp} are t dependent; in practice the measurements did not span a sufficiently large range in t to make this a significant dependence. Experimentally, the x dependence of the data can be parametrized by a single Regge exchange so that the summation sign could be dropped. According to Eq. (1) the cross sections should scale and show no additional s dependence except for the part implicit in σ_{tot}^{cp}. The data were consistent with less than 15% departures from scaling resulting from additional s dependences, except for the "$\pi^+p\to p$" cross section which showed departures from scaling of about 30% from 50 to 175 GeV. In this paper only the data at 140 and 175 GeV are included for this channel.

Table I tabulates the values of the fitted coefficients $|\beta|^2/16\pi s_0^{\,2}$, $\alpha_{\rm eff}$, and $b_{\rm eff}$ determined through a χ^2 minimization procedure. Satisfactory statistical fits were obtained by the form of Eq. (2). The values of $\alpha_{\rm eff}$ are close to those expected by Regge exchange theory. For "$\pi^+p\to K^+$" and "$\pi^-p\to K^-$" the observed values of $\alpha_{\rm eff}$ are small and positive, 0.25 and 0.20, respectively, and for reactions involving nucleon or antinucleon exchange "$\pi^+p\to p$," "$\pi^-p\to\bar{p}$," and "$pp\to\pi^+$," the $\alpha_{\rm eff}$ were approximately -0.6.

TABLE I. Best fit values to the invariant cross section parametrized in the form $d^2\sigma/dt\,dx=(|\beta|^2/16\pi s_0^{\,2})(1-x)^{1-2\alpha_{\rm eff}}\sigma_{tot}^{cp}(M_M^{\,2})e^{b_{\rm eff}t}$.

Channel	Effective $-t$ range (GeV^2)	Laboratory energy range (GeV)	$\lvert\beta\rvert^2/16\pi s_0^{\,2}$ (GeV^{-2})	$\alpha_{\rm eff}$	$b_{\rm eff}$ (GeV^{-2})
$\pi^+ + p\to K^+ +\cdots$	0.1–0.65	50–140	0.155 ± 0.015	0.20 ± 0.06	3.7 ± 0.3
$\pi^- + p\to K^- +\cdots$	0.1–0.65	50–140	0.135 ± 0.014	0.25 ± 0.06	3.7 ± 0.3
$\pi^- + p\to\bar{p} +\cdots$	0.2–0.65	50–175	0.128 ± 0.012	-0.55 ± 0.15	2.0 ± 0.3
$\pi^+ + p\to p +\cdots$	0.2–0.65	140–175	0.240 ± 0.022	-0.50 ± 0.10	3.1 ± 0.5
$p + p\to\pi^+ +\cdots$	-0.2–0.20	50–175	0.270 ± 0.025	-0.65 ± 0.15	4.4 ± 0.5
$p + p\to K^+ +\cdots$	-0.2–0.20	50–175	0.108 ± 0.015	-0.65 ± 0.20	3.0 ± 1.0

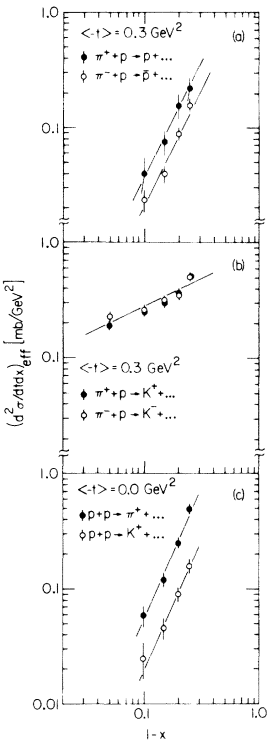

FIG. 2. Plots of $\ln(d^2\sigma/dt\,dx)_{\rm eff}$, as defined by Eq. (3), against $\ln(1-x)$ to display the power-law dependences of the cross sections. The lines through the data points are the results of fits by Eq. (2) with the parameters given in Table I.

Figure 2 shows plots of fits to $\ln(d^2\sigma/dt\,dx)_{\rm eff}$ evaluated at the median t values of the data versus $\ln(1-x)$ in order to display the expected $(1-x)^{1-2\alpha_{\rm eff}}$ dependence. The effective invariant cross section $(d^2\sigma/dt\,dx)_{\rm eff}$ is defined as

$$\left(\frac{d^2\sigma}{dt\,dx}\right)_{\rm eff} = \left(\frac{\sigma_{\rm tot}{}^{cp}(200\ {\rm GeV}^2)}{\sigma_{\rm tot}{}^{cp}(M_M{}^2)}\,\frac{d^2\sigma}{dt\,dx}\right)_{AV}. \qquad (3)$$

The factor $\sigma_{\rm tot}{}^{cp}(M_M{}^2)$ takes out the expected s dependence and the factor $\sigma_{\rm tot}{}^{cp}(200\ {\rm GeV}^2)$ normalizes the cross section to high energies.[6]

Figure 2(a) displays the effective invariant cross sections for the median $-t$ of 0.3 GeV^2 for "$\pi^-p \to \bar{p}$" "$\pi^+p \to p^+$." The "$\pi^+p \to p^+$" is larger by a factor 1.4. In simple Regge theory these two processes should have identical cross sections. The difference in behavior probably arises from u-channel nucleon exchange indicated by the presence of an energy-dependent invariant cross section.

Figure 2(b) plots the effective invariant cross sections for "$\pi^-p \to K^-$" and for "$\pi^+p \to K^+$" and in accord with Regge theory these cross sections are indeed almost identical. Figure 2(c) plots the effective invariant cross sections for the process "$pp \to \pi^+$" and "$pp \to K^+$."

In conclusion, the Regge expression of Eq. (1), as simplified in Eq. (2), gives a good representation of our high-energy inclusive exchange data in the Feynman x range of 0.75 to 0.95.

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