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Diffraction Dissociation of $\pi^{\pm}$, $K^{\pm}$, and $p^{\pm}$ at 100 and 200 GeV/c

R. L. Cool, K. Goulianos, S. L. Segler,[a] H. Sticker, and S. N. White
The Rockefeller University, New York, New York 10021
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We report differential cross sections for $h+p\to X+p$ ($h=\pi^{\pm}, K^{\pm}, p^{\pm}$) at 100 and 200 GeV/$c$ in the region $0.025<|t|<0.095$ (GeV/c)^2 and $M_X^2/s<0.1$.

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We have measured the differential cross sections and the charged multiplicities of the diffraction dissociation of $\pi^{\pm}$, $K^{\pm}$, and $p^{\pm}$ on protons,

$$h+p\to X+p \quad (h=\pi^{\pm},K^{\pm},p^{\pm}), \tag{1}$$

at incident beam momenta of 100 and 200 GeV/c in the kinematic range $0.025<|t|<0.095$ (GeV/c)^2 and $1-x\cong(M_X^2-M_h^2)/s<0.1$, where t is the square of the four-momentum transfer, M_X is the hadron excitation mass, and x is the Feynman scaling variable. In this paper we report on the differential cross sections for $M_X^2>4$ GeV^2.

Previously, measurements in this range were reported for the dissociation of protons on protons[1-4] and deuterons[1,5] and of protons on pions and kaons.[2] It was found that the cross sections $d^2\sigma/dt\,dM_X^2$ vary exponentially with t, fall as $1/M_X^2$ with M_X^2, and scale to the corresponding elastic scattering cross sections. Regge theory ascribes this behavior to the coupling of three Pomerons.[6] The scaling to the elastic cross sections can be understood by assuming that amplitudes factorize into simple products of vertices. Under the assumptions of triple-Pomeron dominance and factorization of the diffractive vertex, the cross sections for Reaction (1) should also vary as $1/M_X^2$, but they should scale to the total rather than the elastic cross sections. Other models, developed more recently, consider dissociation a result of the interaction of hadron constituents.[7] These models predict various features of the diffraction dissociation process, such as M_X^2 dependence, t dependence, charged multiplicity distributions, or relative normalization for different hadrons. Our results on beam dissociation complement previous results on target proton dissociation and therefore provide additional constraints for the various theoretical models.

The experiment was performed in the M6W beam line of the meson laboratory at Fermilab. Experimental details are reported in a paper discussing the elastic scattering results.[8] Pions, kaons, and protons, identified by Čerenkov counters in the beam, interacted in a 40-cm-long, 1-atm gas H_2 target. Recoil protons in the 10- to 50-MeV kinetic energy range were detected on each side of the beam by two drift chambers, which measured the polar angle θ, and by four 60-cm$\times$7.5-cm $\times$2.5-cm-thick scintillation counters, which determined the kinetic energy T_p (Fig. 1). Anti counters, not shown in Fig. 1, assured that the protons stopped in the pulse height counters. The energy and angle of the recoil were used to calculate t and M_X^2 or x,

$$|t|=2M_pT_p, \tag{2}$$

$$1-x=\frac{M_X^2-M_h^2}{s}=\frac{\sqrt{|t|}}{M_p}\left(\cos\theta-\frac{\sqrt{|t|}}{2M_p}\right). \tag{3}$$

The resolution in t was $\sigma_t=0.002$ (GeV/c)^2. The

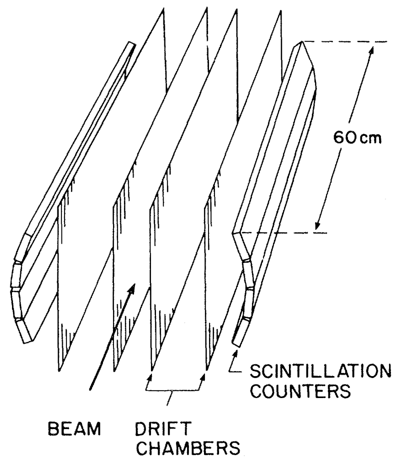

FIG. 1. Recoil detector.

resolution in x at $|t| = 0.05$ $(\mathrm{GeV}/c)^2$ was $\sigma_x = 0.03(1-x)$.

The data were normalized by extrapolating the elastic scattering peaks from our t range to $t=0$ with use of known elastic slopes and by scaling to the optical point with the total cross sections of Carroll *et al.*[9] Since only the elastic slopes for π^-p are determined precisely in this experiment, we used the fitted slopes of Ref. 10 for pp and those of Ref. 2 for π^+p, $K^\pm p$, and $\bar{p}p$. Using Ref. 2 for all the slopes would result in 5% and 10% increases of our π^-p and pp cross sections, respectively. The data of Ref. 2 are at somewhat higher t values than our own. Other more recent measurements[11,12] indicate that the larger values of the slopes that we have used are more appropriate for our t range. The uncertainty in the elastic slopes dominates the systematic uncertainty in the normalization of our data.

The hadron dissociation cross sections obtained vary exponentially with t (Fig. 2) and predominantly as $1/(1-x)$ (Fig. 3). The lines through the data points in these figures represent fits by the form

$$d^2\sigma/dt\,dx = [A/(1-x) + B(1-x)]e^{b(t+0.05)}. \qquad (4)$$

The values for A and B are given in Table I along with the data points.

In the Regge picture, the A term arises from the triple-Pomeron coupling whereas the B term comes from lower-lying trajectories[13] and nondiffractive contributions. The fitted values in Table I show that the triple-Pomeron term dominates hadron dissociation. The A term for $pp \to Xp$ is in excellent agreement with that of Ref. 1 but lies about 10% below that of Ref. 2. The difference is not significant as it can be attributed to the different elastic slopes used in the normalization of the

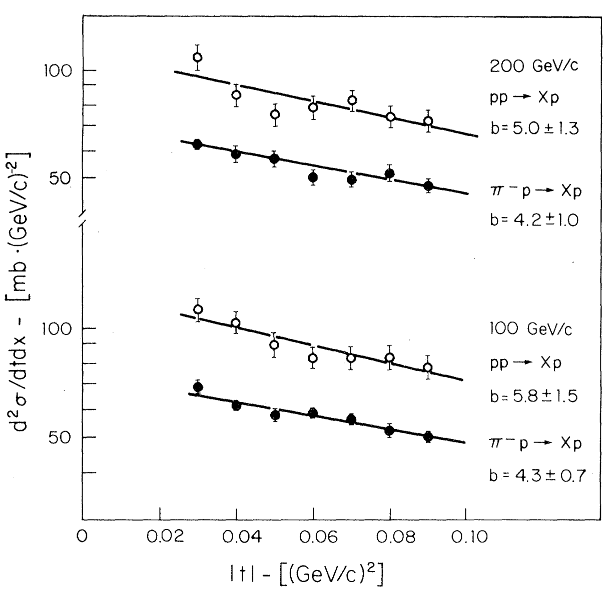

FIG. 2. Differential cross sections vs t for $pp \to Xp$ and $\pi^-p \to Xp$ at 100 and 200 GeV/c in the region 4 GeV$^2/s < 1-x < 0.1$.

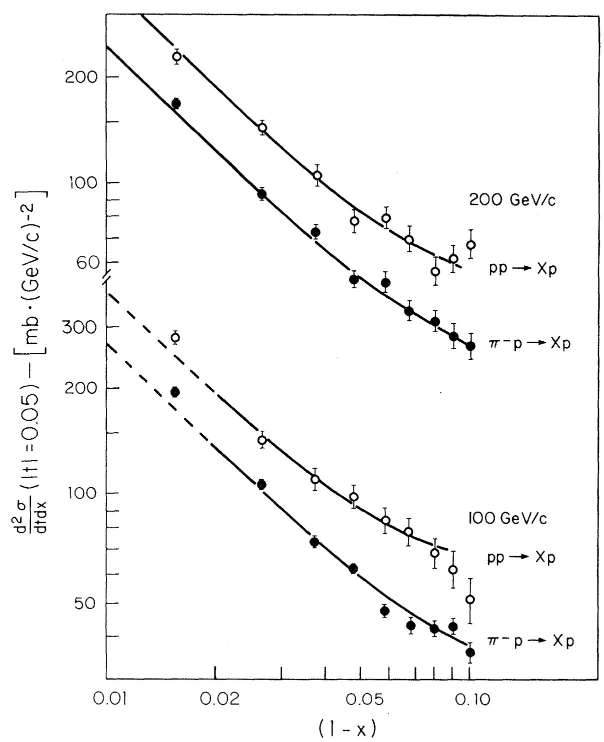

FIG. 3. Differential cross sections vs $1-x$ for $pp \to Xp$ and $\pi^-p \to Xp$ at 100 and 200 GeV/c.

TABLE I. Cross sections for $hp \to Xp$ and fits by the form $d^2\sigma/dt\,dx = [A/(1-x) + B(1-x)]e^{b(t+0.005)}$ (d.o.f. stands for degrees of freedom).

h	p (GeV/c)	$d^2\sigma/dtdx\vert_{\vert t\vert=0.05}$ – [mb·(GeV/c)$^{-2}$]; (1 – x) – [x10^{-2}]: 1.60	2.67	3.73	4.80	5.86	6.93	8.00	9.06	10.13	A mb/(GeV/c)^2	B mb/(GeV/c)^2	χ^2/d.o.f. (5 d.o.f.)	$R = A/\sigma_T$ (GeV/c)$^{-2}$
π^-	100	198.2 ± 3.6	108.0 ± 2.8	74.1 ± 2.5	62.2 ± 2.4	49.5 ± 2.3	42.8 ± 2.2	42.1 ± 2.2	42.6 ± 2.3	36.0 ± 2.4	2.72 ±0.07	98 ± 21	1.7	0.113 ±0.003
K^-	100	202.0 ±19.0	99.0 ±15.0	47.0 ±10.0	45.0 ±11.0	48.0 ±12.0	48.0 ±12.0	47.0 ±12.0	30.0 ±12.0	6.0 ± 9.0	2.01 ±0.33	167 ±107	1.0	0.098 ±0.016
$\bar{p}$	100	238.0 ±30.0	134.0 ±23.0	136.0 ±21.0	161.0 ±23.0	67.0 ±17.0	71.0 ±19.0	39.0 ±15.0	47.0 ±20.0	42.0 ±23.0	4.55 ±0.56	− 33 ±170	2.6	0.108 ±0.013
π^+	100	196.9 ± 9.6	112.1 ± 7.4	61.7 ± 6.5	54.9 ± 6.2	53.5 ± 5.6	47.2 ± 5.2	44.2 ± 5.4	47.3 ± 6.1	30.1 ± 6.1	2.52 ±0.18	162 ± 54	1.6	0.108 ±0.008
K^+	100	125.0 ±30.0	77.0 ±29.0	22.0 ±18.0	43.0 ±20.0	13.0 ±23.0	33.0 ±27.0	11.0 ±23.0	1.0 ± 3.6	0.0 ± .5	1.80 ±0.52	−200 ± 80	0.5	0.095 ±0.027
p	100	282.0 ±11.8	145.5 ± 9.3	112.0 ± 8.4	100.0 ± 7.7	85.8 ± 7.3	79.7 ± 7.1	69.1 ± 7.6	65.4 ± 7.4	51.0 ± 7.5	3.80 ±0.22	306 ± 70	0.4	0.099 ±0.006
π^-	200	170.4 ± 5.0	93.4 ± 3.6	73.4 ± 3.4	54.4 ± 3.1	51.8 ± 3.1	44.2 ± 3.1	41.2 ± 3.1	37.2 ± 3.1	35.1 ± 3.1	2.44 ±0.09	127 ± 29	0.6	0.100 ±0.004
π^+	200	136.6 ±16.7	100.8 ±12.3	75.9 ±11.2	53.0 ± 9.9	31.9 ± 9.6	49.0 ±10.7	44.0 ±11.3	41.1 ±10.8	37.7 ±11.1	2.49 ±0.30	101 ± 99	0.8	0.104 ±0.013
p	200	233.2 ±10.9	146.7 ± 7.9	105.9 ± 7.0	78.8 ± 6.2	80.7 ± 6.5	70.2 ± 6.1	57.0 ± 5.8	62.5 ± 6.6	68.6 ± 7.0	3.68 ±0.19	203 ± 59	0.8	0.094 ±0.005

data. The B term, on the other hand, varies significantly from experiment to experiment. This is not surprising since each experiment which is designed to measure beam dissociation has a different efficiency for detecting other processes that contribute to B, such as target dissociation. Experiments like those performed in the internal target of Fermilab[1,3,5] have no bias against any slow recoils. This experiment suppresses events with more than one large-angle track and thus those events which are likely contributors to B. The suppression factor is model dependent and therefore it is difficult to calculate the correct value of the B term. In contrast, the A term is bias free. Our experiment confirms the $1/M_X^2$ behavior for proton dissociation and establishes it for pion, kaon, and antiproton dissociation as well.

In addition to predicting the correct M_X^2 behavior, the Regge framework provides a way of comparing the absolute values of the diffractive cross sections. Under the assumption of factorization, the triple-Pomeron term [A term of Eq. (4)] can be written as

$$\frac{d^2\sigma_A^{hp}}{dt\,dx} = \frac{\beta_{hP}(0)\beta_{pP}^2(t)G_{PPP}(t)}{16\pi(1-x)} \tag{5}$$

and the total cross section at high energies as

$$\sigma_T^{hp} = \beta_{hP}(0)\beta_{pP}(0), \tag{6}$$

where, for simplicity, we have taken the intercept of the Pomeron trajectory to be $\alpha(0) = 1$ and, because of our small t values, the slope of the trajectory to be $\alpha'(t) = 0$. The ratio of diffractive to total cross section,

$$\frac{d^2\sigma_A^{hp}/dt\,dx}{\sigma_T^{hp}} = \frac{\beta_{pP}^2(t)}{\beta_{pP}(0)}\,\frac{G_{PPP}(t)}{16\pi(1-x)}, \tag{7}$$

should thus be independent of incident particle type. Our results for $R = A/\sigma_T$, listed in Table I and plotted in Fig. 4, show that factorization holds at each beam energy within the experimental uncertainty of $\lesssim 10\%$. The constituent-interaction models will have to explain the accuracy of this factorization rule which arises naturally in the Regge picture.

The triple-Pomeron coupling constant at $t = -0.05$ (GeV/c)^2 can be calculated from Eq. (7) by setting the left-hand side equal to $R/(1-x)$ and obtaining $\beta_{pP}(t)$ from the expression

$$d\sigma_{el}^{pp}(t)/dt = \beta_{pP}^4(t)/16\pi. \tag{8}$$

Using the weighted average of the values of R in

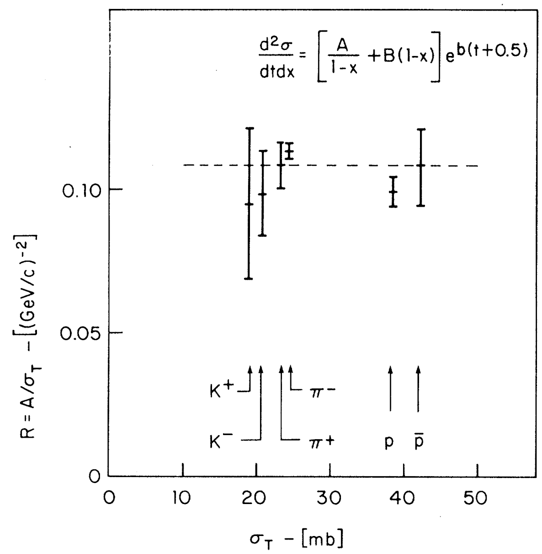

FIG. 4. Diffractive to total cross section ratios vs σ_T for $K^\pm$, $\pi^\pm$, and $p^\pm$ at 100 GeV/c.

Table I at each of the two beam energies and the fitted values of Ref. 9 for the pp elastic scattering cross sections, we obtain $G_{PPP}(t=-0.05)=0.464 \pm 0.011$ mb$^{1/2}$ at 100 GeV/c and 0.414 ± 0.013 mb$^{1/2}$ at 200 GeV/c. If the energy dependence is parametrized as[14] $A(1+B/p)$, we find $B=27.3 \pm 11.4$ GeV/c and $G_{PPP}(s\to\infty, t=-0.05)=0.364 \pm 0.025$ mb$^{1/2}$. The t dependence of $G_{PPP}(t)$ is given by $\exp(b_D{}^{hp}t - \frac{1}{2}b_{el}{}^{pp}t)$, where $b_D{}^{hp}$ is the slope parameter for $hp \to Xp$ [see Eqs. (4), (7), and (8)]. The pp elastic scattering slope in the energy range of 100 to 200 GeV and at $|t| \cong 0.05$ (GeV/c)^2 is[10] approximately equal to 11 (GeV/c)$^{-2}$ or $b_{el}{}^{pp}/2 \cong 5.5$ (GeV/c)$^{-2}$. Figure 2 shows that the diffraction dissociation slopes are compatible with this value. Thus $G_{PPP}(t)$ is independent of t and our final result is $G_{PPP}(t)=0.364 \pm 0.025$ mb$^{1/2}$. This value depends somewhat on the parametrization used to describe the data. When the differences in parametrization are taken into account, our result is consistent with previously published values.[1,14]

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[a]Present address: Fermi National Accelerator Laboratory, Batavia, Ill. 60510.

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