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INELASTIC DIFFRACTIVE SCATTERING AT ENERGIES OF 140 TO 175 GEV

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ABSTRACT

Inelastic differential cross sections have been measured for $\pi^{\pm}$, $K^{\pm}$, and $p^{\pm}$ p at 140 and 175 GeV/c incident momentum over a $|t|$ range 0.05 to 0.6 GeV^2 and covering missing mass region of 2.4 GeV^2 to 9 GeV^2. For M_x^2 greater than 4 GeV^2, the invariant quantity $M_x^2\, d^2\sigma/dtdM_x^2$ was found to be independent of M_x^2 at fixed t and could be adequately described by a simple triple-pomeron form. The values obtained for the triple-pomeron couplings are identical within statistics for all channels.

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We have measured the differential cross sections for the inclusive reactions $a + p \rightarrow a + X$, where $a = \pi^{\pm}$, $K^{\pm}$, or $p^{\pm}$, at 140 and 175 GeV/c incident hadron momenta and covering the kinematical region $0.05 < |t| < 0.7$ GeV^2 and $2.4 < M_x^2 < 9$ GeV^2 corresponding to Feynman values of x from 0.975 to 0.995. This region is expected to be dominated by the diffractive disassociation of the target particle, with the behavior of the cross sections predicted almost completely in terms of single pomeron exchange. With the exception of pp reactions, the inclusive cross sections have not been measured in this kinematical region.

The data for this experiment were obtained at the Fermi National Accelerator Laboratory with the Single Arm Spectrometer in the unseparated M6E beam line in the Meson Laboratory. A general description of the spectrometer and of the beam line have been published.[1] The momenta, angle and particle type of both the incident beam particle and scattered spectrometer particle were measured for each event with a series of hodoscopes and Cerenkov counters.[2,3] Thus, t, the four-momentum transfer between the incident hadron and scattered hadron, and M_x^2, the square of the missing mass, were calculated from the measured parameters. Simultaneously with the scattered events, a random sample of beam triggers was recorded with full hodoscope and Cerenkov counter information providing continuous on-line checks of counter efficiencies. The efficiency and rejection power of the incident particle Cerenkov counter array were sufficiently high so that the contamination due to misidentification of particle type was less than 1% in all cases.

A significant aspect of this focusing spectrometer was a reasonably uniform momentum acceptance over a $\Delta p/p$ range of 4.5%, which allowed

inelastic events for the entire missing mass region considered here to be measured simultaneously with elastically scattered events in the same angular region. The inelastic differential cross sections were obtained by multiplying the ratios of inelastic events to the elastic events by the elastic cross sections[1], taking the appropriate kinematical factors into account. The elastic cross sections were those given in Reference 1. The use of this ratio technique eliminated to a large extent corrections such as target attenuation, counter efficiences, decay in flight, and μ-e contaminations of the beam particles. Corrections to the cross sections due to double scattering in the target and to radiative effects from elastic channels were calculated and found to be small in our missing mass region.

Systematic uncertainties arising from finite t resolution and lack of uniformity of the acceptance were of the order of 4%; uncertainties in the elastic cross sections used for normalization were about 3%. These systematic errors when compounded with statistical errors gave final errors on the data points typically in the range of 6-10%.

Several interesting tests can be made. In the framework of Regge theory a process of the type $a + p \rightarrow a + M_x$ is dominated at large x by pomeron exchanges. Neglecting the slope of the pomeron trajectory and terms associated with other exchanges, this leads to the formula[4]

$$M_x^2 \frac{d^2\sigma}{dt dM_x^2} = \frac{1}{16\pi S_0^2} |\beta_{aap}(t)|^2 \sigma_{tot}^{pp}(M_x^2, t) , \qquad (1)$$

where M_x^2 is the square of the missing mass at which the cross section is measured, $\sigma_{tot}^{pp}(M_x^2,t)$ is the pomeron proton scattering cross section, $\beta_{aap}(t)$ is the coupling between the incident hadron a and the pomeron, and

S_0 is the Regge scale factor. For large values of M_x^2, σ_{tot}^{pp} should become independent of M_x^2 and the invariant cross section should become a function only of t. The coupling constant β_{aap} is determined by the elastic differential cross section:

$$\left(\frac{d\sigma}{dt}\right)_{el}(ap\to ap) = \frac{1}{16\pi S_0^4} \left|\beta_{aap}(t)\right|^2 \left|\beta_{ppp}(t)\right|^2 . \tag{2}$$

Combining Eq. (1) and (2), the "factorization" formula for an incident hadron is obtained

$$M_x^2 \frac{d^2\sigma}{dtdM_x^2} \Big/ \left(\frac{d\sigma}{dt}\right)_{el} = \sigma_{tot}^{pp}(M_x^2,t) \Big/ \sqrt{16\pi(d\sigma/dt)_{pp\to pp}} \tag{3}$$

and this ratio should be independent of the incident particle type.

Figure 1 shows representative data for $M_x^2\ d^2\sigma/dtdM_x^2$ for π^+, p^+, and K^+ as a function of M_x^2 for a number of t regions. Data for π^- is similar to π^+ with p^- and K^- having poorer statistics. Data from 140 GeV/c and 175 GeV/c were combined for this plot since no significant differences exist between these two energies. For $4 < M_x^2 < 9$ GeV^2 the invariant cross section is independent of M_x^2 over the t range of this experiment. In the resonance region, there is an enhancement at all t values.

Figure 2 shows the cross section for $M_x^2\ d^2\sigma/dtdM_x^2$, π^+ and p^+, plotted as a function of t for $4 < M_x^2 < 9$ GeV^2. For $M_x^2 > 4$ the data are well represented by the form

$$M_x^2 \frac{d^2\sigma}{dtdM_x^2} = A \exp\,(Bt + Ct^2) . \tag{4}$$

Table I gives the best fit values for the coefficients A, B, C. The enhancement in the resonance region has a B value approximately 2 GeV^{-2} larger than

the values listed in Table I for $M_x^2 < 4$ GeV^2. The last column of Table I gives the ratios of the inelastic differential cross section to the elastic differential cross section[5] and shows that the hypothesis of factorization is verified for all channels to within experimental uncertainties out to $|t|$ of 0.6 GeV. Approximate factorization is also observed over the resonance region. Our values for A for pp are about 15% higher (~2 standard deviations) than results from the NAL gas jet experiment[6] using $p+D \rightarrow D+X$, but in agreement with preliminary results from the I.S.R.[7] Under the assumptions leading to Eq. (2) a best value for the "pomeron-proton" total cross section of $\sigma^{pp}_{tot}(t) = 2.90 \exp(-1.04t + 0.35t^2)$mb is obtained for this set of reactions.[8] The triple-pomeron coupling constant, r_0, is given by $\sqrt{\sigma_{total\ pp}}\, M_x^2\, d^2\sigma/dtdM_x^2$ $(d\sigma/dt)_{el}$ evaluated at t=0.[9,10] The values of all six reactions are in statistical agreement and the average value of r_0 using $\pi^\pm$ and p^+ data is found to be 0.80 ± 0.03 GeV^{-1} where the error reflects only experimental uncertainties. To summarize:

1. The differential cross section $M_x^2\, d^2\sigma/dtdM_x^2$ is a function of t only above the resonance missing mass region.
2. A pronounced enhancement centered at M_x^2 of 1660 MeV is observed for all projectile particles. Cross sections for this enhancement exhibit an exponential behavior with $|B|$ about 2 (GeV)$^{-2}$ larger than the corresponding values for $M_x^2 > 4$ GeV out to $|t|$ of 0.6 GeV.
3. Factorization of the cross section (Eq. 3) works well, and the value obtained for the triple-pomeron coupling is 0.80 GeV^{-1} for all channels.

We would like to thank the staff at the Fermi National Accelerator Laboratory who helped to maintain the Single Arm Spectrometer. One of us

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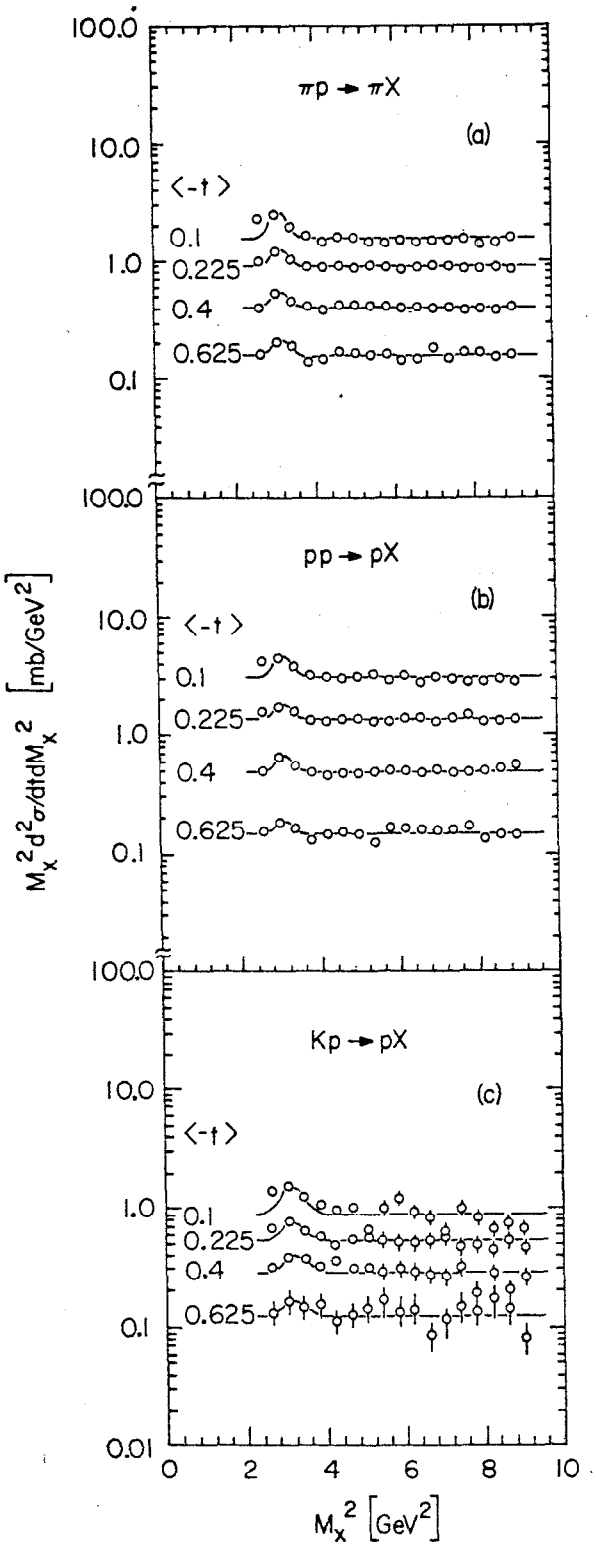
TABLE I. Values of the coefficients A, B, C for various channels where the invariant cross section is given by Eq. (4)

Channel	A (mb/GeV^2)	B (GeV^{-2})	C (GeV^{-4})	$M_x^2 \frac{d^2\sigma}{dt dM_x^2} \Big/ \left(\frac{d\sigma}{dt}\right)_{el}$
π^+	2.37 ± 0.14	4.53 ± 0.15	0.35 ± 0.23	$0.081 \exp(-4.54t - 1.96t^2)$
K^+	1.36 ± 0.08	4.37 ± 0.48	1.00 ± 1.00	$0.071 \exp(-4.14t - 1.30t^2)$
p^+	5.68 ± 0.33	6.64 ± 0.15	1.40 ± 0.21	$0.077 \exp(-4.49t - 1.00t^2)$
π^-	2.40 ± 0.15	5.15 ± 0.18	0.94 ± 0.26	$0.082 \exp(-4.28t - 1.70t^2)$
K^-	1.50 ± 0.15	4.96 ± 0.38	1.00 ± 1.00	$0.068 \exp(-4.29t - 1.75t^2)$
p^-	6.02 ± 0.72	8.03 ± 0.83	2.70 ± 1.00	$0.069 \exp(-4.85t - 1.29t^2)$

FIGURES

FIG. 1. (a) The invariant cross section $M_x^2\ d^2\sigma/dtdM_x^2$ in mb/GeV^2 for $\pi^+p \to \pi^+X$ plotted versus M_x^2 in GeV^2. Figure 1(b) shows the invariant cross section for $p^+p \to p^+X$ and Fig. 1(c) for $K^+p \to K^+X$. Data at 140 and 175 GeV have been combined.

FIG. 2. The invariant cross section $M_x^2\ d^2\sigma/dtdM_x^2$ in mb/GeV^2 averaged over the range 4 GeV$^2 \leq M_x^2 \leq$ 9 GeV^2 for $\pi^+p \to \pi^+X$ and $p^+p \to p^+X$. versus $-t$ in GeV^2. Data at 140 GeV and 175 GeV are combined together. The curve given for the photon data uses the fit parameters of Table I. The dotted curve is directly scaled from the proton data by the elastic scattering factor $(d\sigma/dt)_{pi}/(d\sigma/dt)_p$ to show the "scaling" prediction versus the experimental data for the π^+p channel.


πp → πX
(a)
⟨-t⟩
0.1
0.225
0.4
0.625
pp → pX
(b)
Kp → pX
(c)
100.0
10.0
1.0
0.1
0.01
0
2
4
6
8
10
$M_x^2 d^2\sigma/dtdM_x^2$ [mb/GeV^2]
M_x^2 [GeV^2]

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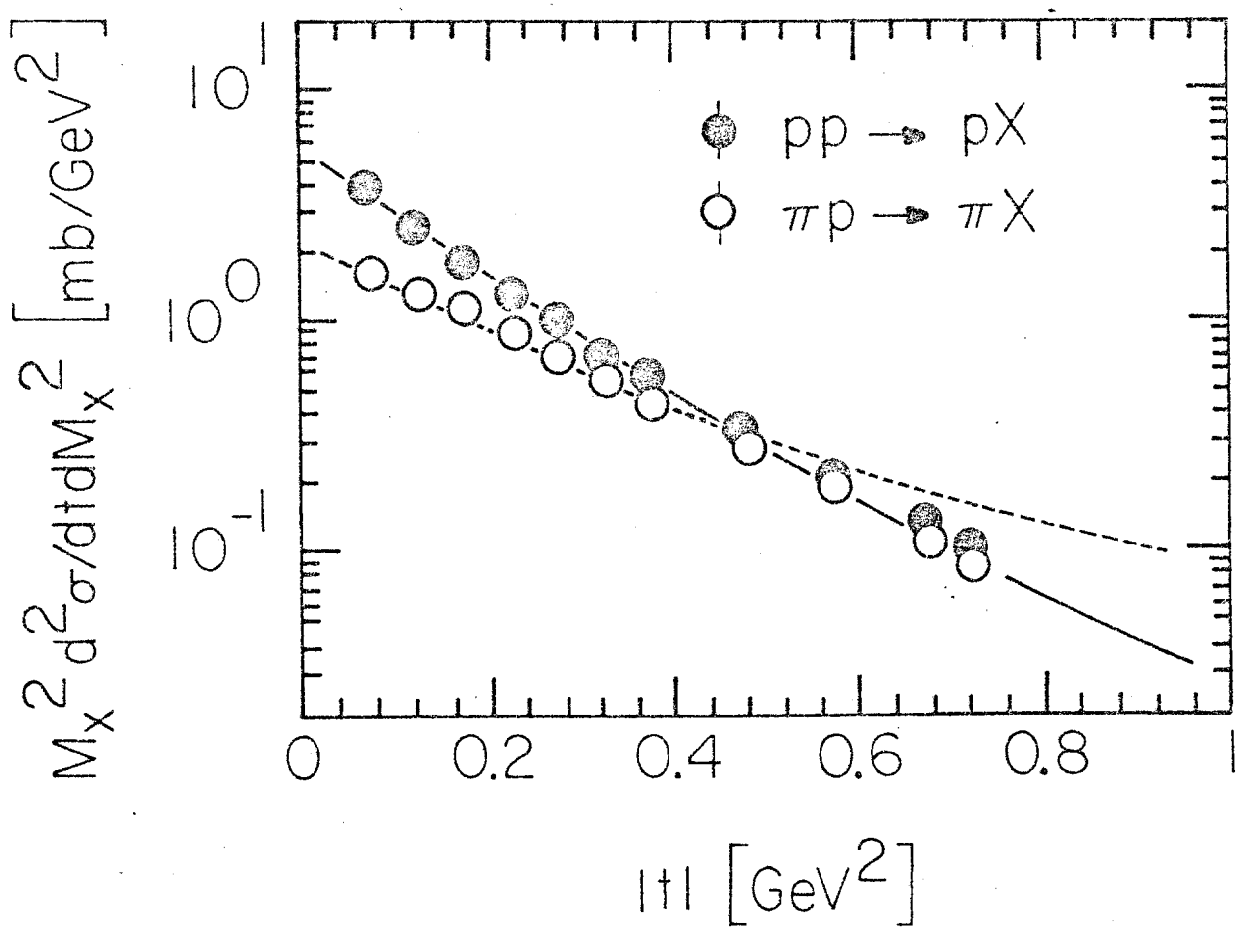
$M_X^2 d^2\sigma/dt dM_X^2$ [mb/GeV^2]
10^1
10^0
10^{-1}
pp → pX
πp → πX
0
0.2
0.4
0.6
0.8
1
|t| [GeV^2]

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