INELASTIC DIFFRACTIVE SCATTERING AT ENERGIES OF 140 TO 175 GEV

D. S. Ayres and R. Diebold
Argonne National Laboratory, Argonne, IL 60439

D. Cutts, R. E. Lanou, L. J. Levinson, and J. T. Massimo
Brown University, Providence, RI 02912

J. Litt and R. Meunier
CERN, Geneva, Switzerland

B. Gittelme and M. Sogard
Cornell University, Ithaca, NY 14850

A. E. Brenner, J. E. Elias and G. Mikenberg
Fermi National Accelerator Laboratory, Batavia, IL 60510

C. De Marzo, L. Guerriero, P. Lavopa, G. Maggi,
F. Posa, G. Selvaggi, P. Spinelli and F. Waldner
Istituto Nazionale di Fisica Nucleare, Sezione di Bari, Italy

D. S. Barton, J. Butler, J. Fines, J. I. Friedman
H. W. Kendall, B. Nelson, L. Rosenson and R. Verdier
Massachusetts Institute of Technology, Cambridge, MA 02139

Stanford Linear Accelerator Center, Stanford, CA 94305

E. C. Loh
University of Utah, Salt Lake City, UT 84112

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 \( M_x^2 \frac{d^2\sigma}{dt dM_x^2} \) 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.

*Work supported in part by the Energy Research and Development Administration, the National Science Foundation, and INFN (Italy).

(Submitted to Phys. Rev. Letters)
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\textsuperscript{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 efficiencies, decay in flight, and \mu-\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\textsuperscript{4}

\[
M_x^2 \frac{d^2\sigma}{dtdM_x^2} = \frac{1}{16\pi S_0^2} |\beta_{aap}(t)|^2 \sigma_{pp\text{ tot}}(M_x^2,t)^2,
\]

where \( M_x^2 \) is the square of the missing mass at which the cross section is measured, \( \sigma_{pp\text{ tot}}(M_x^2,t) \) is the pomeron proton scattering cross section, \( \beta_{aap}(t) \) is the coupling between the incident hadron \( a \) and the pomeron, and
So is the Regge scale factor. For large values of $M_x^2$, $\sigma_{\text{tot}}^{p+}$ should become independent of $M_x^2$ and the invariant cross section should become a function only of $t$. The coupling constant $\beta_{\text{app}}$ is determined by the elastic differential cross section:

$$\frac{d\sigma}{dt}_{el} (ap+ap) = \frac{1}{16\pi s_0} |\beta_{\text{app}}(t)|^2 |\beta_{\text{ppp}}(t)|^2 .$$

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

$$M_x^2 \frac{d^2\sigma}{dtdM_x^2} \left/ \frac{d\sigma}{dt}_{el} \right. = \frac{\sigma_{\text{tot}}^{p+}(M_x^2,t)}{16\pi (d\sigma/dt)_{pp+pp}^{p+pp}}$$

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

Figure 1 shows representative data for $M_x^2 \frac{d^2\sigma}{dtdM_x^2}$ for $p^+$, $p^+$, and $K^+$ as a function of $M_x^2$ for a number of $t$ regions. Data for $\pi^-$ is similar to $\pi^+$ 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 $M_x^2 \frac{d^2\sigma}{dtdM_x^2}$, $\pi^+$ 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

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

Table I gives the best fit values for the coefficients $A$, $B$, $C$. The enhancement in the resonance region has a $B$ value approximately $7$ GeV$^{-2}$ larger than
the values listed in Table I for $M_x^2 < 4 \text{ GeV}^2$. 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 ($\sim 2$ standard deviations) than results from the NAL gas jet experiment$^6$ using $p+D\to D+X$, 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 

$$\sigma_{pp}^{\text{tot}}(t) = 2.90 \exp(-1.04t + 0.35t^2)\text{mb}$$

is obtained for this set of reactions.$^8$ The triple-pomeron coupling constant, $r_0$, is given by 

$$r_0 = \frac{\sqrt{\pi}}{\int_{-1}^{1} \frac{d^2\sigma/dtdM_x^2}{\text{el}}(dt)}_{\text{el}}$$

evaluated at $t=0.9,10$ The values of all six reactions are in statistical agreement and the average value of $r_0$ using $\pi^+$ and $p^+$ data is found to be $0.80 \pm 0.03 \text{ GeV}^{-1}$ where the error reflects only experimental uncertainties. To summarize:

1. The differential cross section $M_x^2 \frac{d^2\sigma}{dtdM_x^2}$ 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 $M_x^2 > 4 \text{ GeV}$ 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
(E.C.L.) would like to thank Professors William Frazer and James Ball for many helpful discussions. We would also like to express our appreciation to our technical support personnel for their assistance.
REFERENCES

1. Fermilab Single Arm Spectrometer Group, Phys. Rev. Lett. 35, 1195 (1975). (This reference also includes examples of raw inelastic scattering spectra from which the results of this paper are derived.)


5. The ratios are determined directly by this experiment and are independent of any assumptions as to the elastic cross sections.


8. It is estimated that the inclusion of terms associated with other exchanges and a pomeron slope of - 0.2 GeV^{-2} can lead to a reduction of about 20% of the value of \sigma_{tot}^{P\bar{P}}.


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

<table>
<thead>
<tr>
<th>Channel</th>
<th>$A$ (mb/GeV$^2$)</th>
<th>$B$ (GeV$^{-2}$)</th>
<th>$C$ (GeV$^{-4}$)</th>
<th>$M_x^2 \frac{d^2\sigma}{dtdM_x^2} \rightarrow \frac{d\sigma}{dt}_{el}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^+$</td>
<td>$2.37 \pm 0.14$</td>
<td>$4.53 \pm 0.15$</td>
<td>$0.35 \pm 0.23$</td>
<td>$0.081 \exp(-4.54t-1.96t^2)$</td>
</tr>
<tr>
<td>$K^+$</td>
<td>$1.36 \pm 0.08$</td>
<td>$4.37 \pm 0.48$</td>
<td>$1.00 \pm 1.00$</td>
<td>$0.071 \exp(-4.14t-1.30t^2)$</td>
</tr>
<tr>
<td>$p^+$</td>
<td>$5.68 \pm 0.33$</td>
<td>$6.64 \pm 0.15$</td>
<td>$1.40 \pm 0.21$</td>
<td>$0.077 \exp(-4.49t-1.00t^2)$</td>
</tr>
<tr>
<td>$\pi^-$</td>
<td>$2.40 \pm 0.15$</td>
<td>$5.15 \pm 0.18$</td>
<td>$0.94 \pm 0.26$</td>
<td>$0.082 \exp(-4.28t-1.70t^2)$</td>
</tr>
<tr>
<td>$K^-$</td>
<td>$1.50 \pm 0.15$</td>
<td>$4.96 \pm 0.38$</td>
<td>$1.00 \pm 1.00$</td>
<td>$0.068 \exp(-4.29t-1.75t^2)$</td>
</tr>
<tr>
<td>$p^-$</td>
<td>$6.02 \pm 0.72$</td>
<td>$8.03 \pm 0.83$</td>
<td>$2.70 \pm 1.00$</td>
<td>$0.069 \exp(-4.85t-1.29t^2)$</td>
</tr>
</tbody>
</table>
FIGURES

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

FIG. 2. The invariant cross section $M_x^2 \frac{d^2\sigma}{dt dM_x^2}$ in mb/GeV$^2$ averaged over the range $4 \text{ GeV}^2 \leq M_x^2 \leq 9 \text{ GeV}^2$ for $\pi^+ p \rightarrow \pi^+ X$ and $p^+ p \rightarrow p^+ X$ 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 $\pi^+ p$ channel.