[12]Because of the normalization procedure a previous experiment utilizing charge asymmetries (Ref. 6) would not have been sensitive to this systematic effect.

[13]This procedure was made possible by the fact that electron trajectories within the Cherenkov counter were, to a first approximation, independent of the sign of the electron charge. The relative numbers of in- and out-bending events varied widely over the aperture of the Cherenkov counters. It was for this reason that the averaging was done over relatively small elements of "Cherenkov phase space."

[14]D. Dorfan *et al.*, Phys. Rev. Lett. 30, 876 (1973).

[15]P. Steffen *et al.*, reported by C. Rubbia, in *Proceedings of the Sixteenth International Conference on High Energy Physics, The University of Chicago and National Accelerator Laboratory, 1972,* edited by J. D. Jackson and A. Roberts (National Accelerator Laboratory, Batavia, Ill., 1973), Vol. 4, p. 157.

Measurement of $p+p \to p+X$ between 50 and 400 GeV*

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We present measurements of the invariant cross section for the inclusive reaction $p+p \to p+X$ in the region $0.14<|t|<0.38$ GeV^2, $100<s<750$ GeV^2, and $0.80<x<0.93$.

In a recent Letter[1] we presented the first results of our study of the reaction

$$p+p \to p+X \quad (1+2\to 3+X) \tag{1}$$

using the internal H_2 jet target at the National Accelerator Laboratory (NAL). The results of Ref. 1 confirmed the phenomenon of diffractive excitation of the target (beam) particle into high masses, first observed at the CERN intersecting storage rings (ISR).[2] Furthermore, by studying the energy dependence of Reaction (1) for $40 \leq P_1 \leq 260$ GeV we established the presence of a large energy-independent component which we identified with a nonvanishing triple Pomeron coupling[3] for values of the momentum transfer $t=-0.33$ and -0.45 GeV^2. The results presented here extend our previous measurements to lower t values (-0.14 GeV^2) and higher energies ($P_1=400$ GeV). The experimental setup is similar to the earlier experiment which is described in Ref. 1. The main modification consisted in replacing the Al absorbers which determined two momentum intervals for the recoil nucleon by a total-absorption scintillation counter. The energy and velocity of the recoil particles are measured by pulse height in the 20-cm-long absorption counter and time of flight over 186 cm. The resulting scatter plot of pulse height versus time of flight has two distinct bands corresponding to recoil protons and pions. The pulse-height information is used only to remove pions. The remaining events in each 0.7-nsec-wide time-of-flight bin are summed over pulse height and represent the number of protons over the corresponding four-momentum transfer interval. This procedure avoids the loss of proton events through interactions in the absorption counter which lead to inferior pulse heights. We applied a small t-dependent correction to the raw data in order to take into account the loss of events through multiple Coulomb scattering in the material in front of the total absorption counter. This effect was calculated by a Monte Carlo program and checked empirically by varying the amount of material between the target and absorption counter. The correction amounted to an 8% increase at our lowest $|t|$ value and was negligible for $|t|>0.28$ GeV^2.

Our results are expressed in terms of the invariant cross section $sd^2\sigma/dt\,dM^2$ which is a function of the three Lorentz-invariant quantities[1]

$$s \simeq 2mE_1, \tag{2a}$$

$$t=-2m(E_3-m), \tag{2b}$$

$$x=1-M_X^2/s \simeq (E_3-P_3\cos\theta_3)/m, \tag{2c}$$

where s, t, and M_X^2 are the squares of the center-of-mass energy, the four-momentum transfer, and the missing mass, respectively. The angle between incident and recoil proton is θ_3

and m is the proton mass. Typical experimental full-width resolutions in these quantities are $\Delta s \simeq 30$ GeV^2, $\Delta t \simeq 0.06$ GeV^2, and $\Delta x \simeq 0.012$. Note that in our kinematic region the variable x defined by Eq. (2c) is to a very good approximation equal to the Feynman variable $P_\parallel{}^*/P_{\parallel\,\max}{}^*$.

The absolute normalization of the data presented here is obtained by monitoring the rate of elastically scattered protons in a small solid state detector[4] situated at a lab angle of 85.5° to the beam axis. For elastic scattering at this angle we have $|t| \simeq 0.022$ GeV^2. The pulse height spectrum in the solid state detector shows a clean elastic signal on top of a small background. Typical signal-to-background ratios are 20 to 1. For the rate of elastic events we have

$$N_{\rm el} = L\frac{d\sigma}{d\Omega}\Delta\Omega = \frac{L}{2\pi}\frac{d\sigma}{dt}\left(\frac{P_1}{E_1+m}\right)^2 8m^2\cos\theta\,\Delta\Omega, \tag{3}$$

where $\Delta\Omega$ is the solid angle subtended by the solid state detector at a laboratory angle θ to the beam. L is the luminosity and $d\sigma/d\Omega$ and $d\sigma/dt$ are the elastic differential cross sections.

For $d\sigma/dt$ we use the form

$$\frac{d\sigma}{dt}(s,t) = \frac{d\sigma}{dt}(s,0)e^{bt} \tag{4}$$

with $b(s) = 8.3 + 0.55\ln s$ as determined in our energy range by Bartenev *et al.*[4] By combining Eqs. (3) and (4) with the optical theorem we obtain for the luminosity

$$L = N_{\rm el}\left[\sigma_T{}^2\left(\frac{mP_1}{E_1+m}\right)^2\frac{(1+\alpha^2)e^{bt}}{4\pi^2}\cos\theta\,\Delta\Omega\right]^{-1}, \tag{5}$$

where $\alpha(s)$ is the ratio of real to imaginary part of the forward elastic scattering amplitude and $\sigma_T(s)$ is the total pp cross section. Using the measured rate of elastic events we can then calculate the luminosity which allows us to obtain the overall normalization of our data on Reaction (1). For $\sigma_T(s)$, for which there are no accurate measurements over our energy range, we use the analytic parametrization of Bourrely and Fischer[5] which gives 38.5 mb at $P_1 = 50$ GeV/c and 40 mb at $P_1 = 400$ GeV/c in agreement with total-cross-section measurements from Denisov *et al.*[6] and the CERN ISR.[7] For $\alpha(s)$ we again use the parametrization of Rev. 5. It should be noted that the experimental uncertainties on $\alpha(s)$ and $b(s)$ over our energy range have at most a

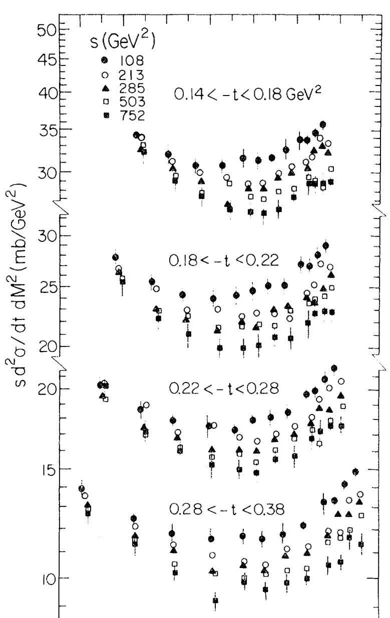

FIG. 1. Invariant cross sections as a function of x at five s values over four t intervals. Errors for the three intermediate energies are similar to those shown for the two extreme energies.

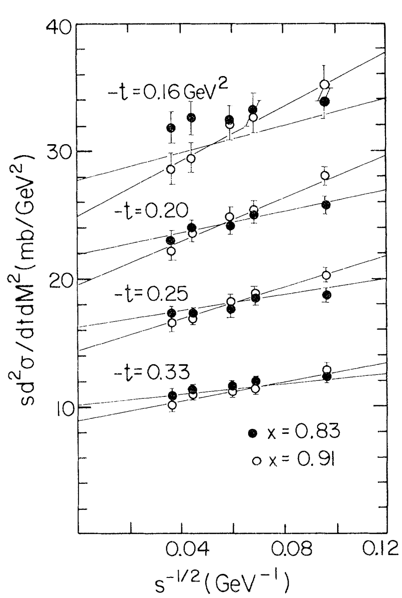

FIG. 2. Data at two fixed values of x illustrating the s dependence of the form $C(1+B/\sqrt{s})$ with slope B which increases with x. The straight lines are fits at fixed x of the form (6) to the data at all s and t. At $x = 0.83$, $t = -0.16$ GeV^2, the fit is systematically 5% below the data indicating the deviation of the data from a simple exponential t dependence.

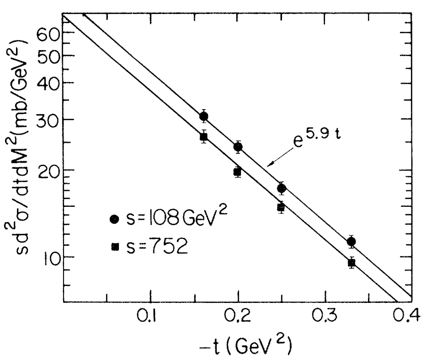

FIG. 3. Data at fixed $x=0.87$ plotted against t. The two extreme energies can be fitted by the same exponential $e^{5.9t}$.

2% effect on our normalization. The largest uncertainty in the relative normalization between different energies[8] comes from $\sigma_T(s)$ while the errors in the overall normalization of our data come mainly from uncertainties in the effective area of the solid state detector and the acceptance of our recoil spectrometer. We estimate the error on the relative normalization between our two extreme energies to be $\pm 5\%$ and the uncertainty in the overall normalization to be $\pm 15\%$.

Our data at five s values and over four t intervals are plotted as a function of x in Fig. 1. The statistical errors on each point are $\pm 1\%$ to $\pm 2\%$ to which we have added quadratically systematic uncertainties of $\pm 2.5\%$. We observe a clear minimum around $x=0.88$ which moves very little with s or t. We also observe that the energy dependence of the invariant cross section increases with increasing x. This feature is present for all four t intervals and is emphasized in Fig. 2 where we plot the invariant cross section against $s^{-1/2}$ for $x=0.83$ and 0.91. The data points of Fig. 2 can be fitted by straight lines indicating a dependence on s of the form $C(1+B/\sqrt{s})$, where C and B are functions of x and t only. Finally, in Fig. 3 we show the invariant cross section at fixed $x=0.87$ as a function of t for our two extreme s values. Although there is a slight indication that the slope parameter b increases with decreasing $|t|$, in our t range the t distribution can be fitted by a simple exponential e^{bt}. As can be seen from Fig. 3, the slope parameter b is independent of s indicating that in the form $C(1+B/\sqrt{s})$ the energy-dependent term $B/\sqrt{s}$ is a function of x only while C is a function of x and t.

The above observations lead to a simple parametrization for the s, t, and x dependence of the data which has the form

$$\frac{sd^2\sigma}{dt\,dM^2}=A(x)e^{b(x)t}\left(1+\frac{B(x)}{\sqrt{s}}\right). \tag{6}$$

TABLE I. The coefficients A, B, and b resulting from a fit of the form (6) to the data of this experiment.

$x=1-M_X^2/s$	A (mb/GeV^2)	B (GeV)	b (GeV^{-2})
0.81	77 ± 8	1.1 ± 0.7	5.7 ± 0.3
0.83	71 ± 7	1.9 ± 0.7	5.9 ± 0.3
0.85	64 ± 6	2.5 ± 0.7	5.9 ± 0.3
0.87	61 ± 5	3.0 ± 0.6	5.9 ± 0.3
0.89	62 ± 4	3.6 ± 0.5	6.0 ± 0.3
0.91	66 ± 3	4.3 ± 0.4	6.1 ± 0.3

The resulting fits of Eq. (6) to our data are shown in Figs. 2 and 3 and the values of A, B, and b for six intervals of x are given in Table I. It should be noted that although Eq. (6) is a convenient representation of the data within our kinematic region, it should not be used to extrapolate our results beyond our t region because of the known[2] decrease of the slope parameter b at large t.

In the limit $s\to\infty$ expression (6) reduces to Ae^{bt} and from Table I we see that at fixed t this term goes through a minimum around $x=0.88$. We also note that at $s=100$ GeV^2 the energy-dependent part $B/\sqrt{s}$ represents 11% and 43% of the total cross section at $x=0.81$ and 0.91, respectively, while at $s=750$ GeV^2 this part represents 4% and 16%. This implies that in order to observe any further variation in the energy range of the CERN ISR ($550\leq s\leq 3130$ GeV^2) the relative normalization errors between different energies must be smaller than 10%. This point emphasizes the importance of the energy range $50\leq s\leq 750$ GeV^2 in future studies of the approach to the scaling limit.

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[3]For definitions and references see Ref. 1.

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[8]In Ref. 1 the overall normalization was determined indirectly by extrapolating to measurements of Reaction (1) at 24 and 30 GeV. For the relative normalization between different energies we had assumed a constant total cross section. In view of the recent evidence for a rising total cross section a small s-dependent correction factor should be applied to the data of Ref. 1. The factor is simply $[\sigma_T/(38.5\text{ mb})]^2$ and amounts to a $\sim 5\%$ increase at the highest energy data of Ref. 1. This small correction reduced by $\sim 30\%$ the value of the parameter B in $A(1+B/\sqrt{s})$ which was used to fit the data in Ref. 1.

Determination of Triple Regge Couplings from a Study of the Reaction $p+p\to p+X$ between 50 and 400 GeV*

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We present an analysis, in the framework of the triple Regge model, of our recent experimental results on the reaction $p+p\to p+X$ between 50 and 400 GeV.

In a recent experiment[1] at the National Accelerator Laboratory we have studied the single-particle distribution for the inclusive reaction

$$p+p\to p+X \quad (1+2\to 3+X). \tag{1}$$

In the last two years several authors[2] have attempted to describe this reaction in terms of triple Regge couplings. Near the kinematic limit for particle 3, where $s \gg M^2 \gg 1$ GeV^2 and t is small (s, M^2, and t are, respectively, the squares of the center-of-mass energy, the mass of X, and the four-momentum transfer between particles 2 and 3), the combination of Regge phenomenology with the generalized optical theorem leads to a prediction for the invariant cross section for particle 3 which is[3]

$$\frac{s d^2\sigma}{dt\, dM^2}=\frac{s_0}{s}\sum_{ijk} G_{ijk}(t)\left(\frac{s}{M^2}\right)^{\alpha_i(t)+\alpha_j(t)}\left(\frac{M^2}{s_0}\right)^{\alpha_k(0)}. \tag{2}$$

In the triple Regge (TR) formula (2), $G_{ijk}(t)$ is the product of a Reggeon-Reggeon-Reggeon coupling, $g_{ijk}(t)$, and three particle-particle-Reggeon couplings, i.e., $G_{ijk}(t)=g_{ijk}(t)\beta_{i23}(t)\beta_{j23}(t)\times\beta_{k11}(0)$. In what follows we shall refer to $G_{ijk}(t)$ as the TR couplings. The functions $\alpha_i(t)=\alpha_{0i}+\alpha_i't$ are Regge trajectories and, as usual, we take the scale factor $s_0=1$ GeV^2. We shall also make use of the Feynman variable $x\simeq 1-M^2/s$.

The TR formula (2) is an asymptotic expression and in the absence of a detailed theory the range of s, M^2, and t over which it is valid can only be guessed from a phenomenological analysis. In order to do this, however, we must know how many terms to allow in Eq. (2) and also what intercepts α_{0i} and slopes α_i' to use for the various trajectories. In principle all combinations ijk which are not forbidden by quantum-number conservation can contribute to Eq. (2), the only re-