Letter.

We are grateful to many members of the Fermilab staff and in particular to the personnel of the internal target section for their cooperation in the planning and execution of this experiment. We acknowledge the support of the technical staff at Rockefeller University and the University of Rochester. The Soviet members of our team express their gratitude to the U.S.S.R. State Committee for Atomic Energy and the Joint Institute for Nuclear Research, Dubna, for their generous support.

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[1]Preliminary results from this experiment are reported by Y. Akimov *et al.*, in *Proceedings of the Seventeenth International Conference on High Energy Physics, London, England, 1974,* edited by J. R. Smith (Rutherford High Energy Laboratory, Didcot, Berkshire, England, 1975).

[2]Y. Akimov *et al.*, following Letter [Phys. Rev. Lett. 35, 766 (1975)].

[3]V. Bartenev *et al.*, Adv. Cryog. Eng. 18, 460 (1973).

[4]By the use of a 5-mm lithium-drifted detector as the second detector of a stack, the t range was extended to $|t| \simeq 0.12$ (GeV/c)^2 in some cases.

[5]Y. Akimov *et al.*, Zh. Eksp. Teor. Fiz. 48, 767 (1965) [Sov. Phys. JETP 21, 507 (1965)]; Y. Akimov *et al.*, Yad. Fiz. 4, 88 (1965) [Sov. J. Nucl. Phys. 4, 63 (1967)]; V. Bartenev *et al.*, Phys. Rev. Lett. 31, 1088, 1367 (1973); and references given in these papers.

[6]V. Bartenev *et al.*, Phys. Lett. 51B, 299 (1974).

[7]L. S. Zolin *et al.*, Yad. Fiz. 18, 56 (1973) [Sov. J. Nucl. Phys. 18, 30 (1974)].

[8]Y. Akimov *et al.*, "Proton-Deuteron Elastic Scattering at Small Momentum Transfer from 50 to 400 GeV/c" (to be published).

[9]We point out that, although b_0 as extracted from elastic scattering is strongly correlated to c_0, the values for b_N and for the extracted nucleon cross sections are not affected by variations of the parameters b_0 and c_0 within the constraint imposed by the elastic-scattering data (Refs. 7 and 8).

[10]R. M. Edelstein *et al.*, Phys. Rev. D 5, 1073 (1972).

Diffraction Dissociation of High-Energy Protons in p-d Interactions*

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We report results from a measurement of the inclusive process $p + d \rightarrow X + d$ in the region $0.03 < |t| < 0.12$ (GeV/c)^2 and 5 GeV$^2 < M_X^2 \lesssim 0.11 p_{\rm lab}$ for incident proton momenta from 150 to 400 GeV/c. We find that in this region, the differential cross section $d^2\sigma/dt\,dM_X^2$ varies only slowly with energy, falls exponentially with $|t|$, and behaves to a good approximation as $1/M_X^2$. The measurement was performed at Fermilab by detecting slow-recoil deuterons from a deuterium-gas-jet target placed at the internal beam of the accelerator.

As part of an experimental study[1,2] of the low-four-momentum-transfer interaction of high-energy protons with a deuterium-gas-jet target in the internal beam at Fermilab, we have measured the differential cross section $d^2\sigma/dt\,dM_X^2$ for the inelastic inclusive reaction

$$p + d \rightarrow X + d \tag{1}$$

in the region $0.03 < |t| < 0.12$ (GeV/c)^2 and (5 GeV^2/$s < M_X^2/s \lesssim 0.03$, where $s \simeq 2m_d p_{\rm lab}$, for incident proton momenta from 150 to 400 GeV/c. In this region of small $|t|$ and small M_X^2/s, Reaction (1) is expected to be dominated by diffraction dissociation of the incoming proton. Results on the excitation of protons into the resonance region ($M_X^2 < 5$ GeV^2) are presented in the preceeding Letter.[2] Here we discuss the diffraction dissociation of protons into the continuum of states with $M_X^2 > 5$ GeV^2, up to $M_X^2/s \simeq 0.03$ or $M_X^2 \sim 40$ GeV^2 for our highest proton momentum.

The apparatus and experimental technique are described in detail in Refs. 1 and 2. A deuterium gas jet was pulsed to intercept the internal beam at predetermined times during the acceleration cycle, thus selecting the desired beam momenta. The full width at half-maximum of the jet at beam height was ~ 1.2 cm. Slow-recoil deuterons were detected by stacks of two surface-barrier silicon solid-state detectors placed on a movable carriage at a distance 2.5 m from the target near 90° to the beam. The size of the detectors, which were collimated to a circular area of ~ 1 cm^2, and the width of the jet result in an angular resolution for the recoils of about ± 3 mrad. The thickness of the front detector in each stack was 0.2 mm and that of the rear detector either 1.5 or 5 mm. Since only those recoils that stop in the rear detector were accepted, deuterons were identified unambiguously by measuring their energy loss in each detector.

The t value is obtained from the measured kinetic energy T of the deuteron, $|t| = 2m_d T$. The scaling variable x, defined as $p_{\parallel}/p_{\max}$ of the deuteron in the c.m. system, is given by

$$1 - x \simeq \frac{M_X^2 - m_p^2}{s} \simeq \frac{|t|^{1/2}}{m_d}\left(\sin\omega - \frac{|t|^{1/2}}{2m_d}\right), \tag{2}$$

where ω is the recoil angle measured from 90°. For a given $|t|$, a detector placed at an angle ω samples the same x region (or, for large M_X^2, the same M_X^2/s region) independent of the incident proton monentum. In this experiment, the angle ω was kept $\lesssim 17°$ corresponding to $x \gtrsim 0.97$ or $M_X^2/s \lesssim 0.03$. The mass M_X^2 is calculated by use of Eq. (2). The resolution in M_X^2 is dominated by the uncertainty in the recoil angle, $\Delta M_X^2 = 2p_{\rm lab}|t|^{1/2}\Delta\omega$. Over the range of t and $p_{\rm lab}$ covered by the data in this report, ΔM_X^2 varies from 0.15 to 0.8 GeV^2.

The counts ΔN within a t interval $\Delta|t| = 2m_d\Delta T$ registered in a detector stack at an angle ω were

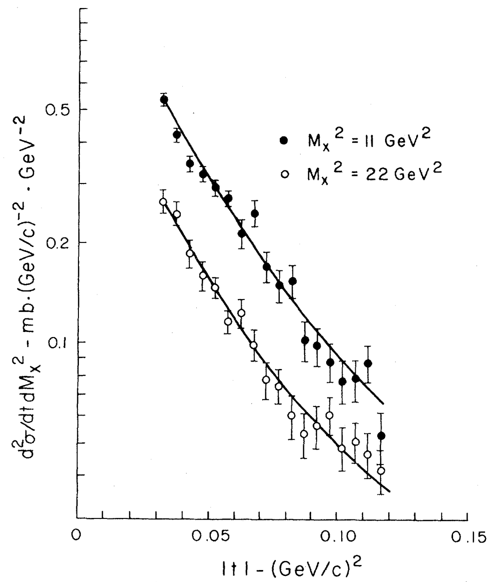

FIG. 1. Differential cross sections $d^2\sigma(p + d \to X + d)/dt\,dM_X^2$ versus t for fixed M_X^2 ($p_{\rm lab}$=275 GeV/c). The lines are best fits to the data using Eq. (4) of the text.

converted to absolute differential cross sections $d^2\sigma/dt\,d(M_X^2/s)$ by normalizing to elastic scattering[1,2] with a detector stack fixed at a small angle ω. At each s value, the normalization uncertainty was estimated to be about ± 3%. The statistical errors, typically a few percent, were combined in quadrature with a 1% systematic error, which is the estimated uncertainty in the area calibration of the detectors and the fluctuation of dead-time losses during the experiment.[1] A background of recoil deuterons was observed in the unphysical region $M_X^2 < m_p^2$. The measured level was ~ 3×10^{-4} of the elastic counts at the same value of $|t|$, independent of angle over the range of angles at which it could be observed. This behavior is consistent with that to be expected in our apparatus from rescattering of elastic deuteron recoils. This background is adequately fitted by

$$\left.\frac{d^2\sigma}{dt\,d(M_X^2/s)}\right|_{\rm background} = (19 \pm 3)\exp[-(30 \pm 12)(|t| - 0.05)]\ {\rm mb}\ ({\rm GeV}/c)^{-2}. \tag{3}$$

This correction, which varies between 3 and 15%, has been applied to the data.

Typical differential cross sections for fixed M_X^2 are shown in Fig. 1. These cross sections exhibit a steep t dependence as expected for coherent scattering from deuterons. Within the range of M_X^2 covered in this experiment, we find no evidence for a turnover in the t distributions down to values of $|t| \simeq 0.03$. Guided by p-d elastic scattering,[1] we have fitted the differential cross sections with the form

$$d^2\sigma/dt\,dM_X^2 = a(s, M_X^2)\exp[-b(s, M_X^2)(|t| - 0.05) + c(t^2 - 0.05^2)], \tag{4}$$

TABLE I. Differential cross sections[a] at $|t|=0.05$ and slope parameter[b] for $p+d\rightarrow X+d$.

p_{lab} →	150 GeV/c		275 GeV/c		385 GeV/c	
M_x^2-GeV^2	$d^2\sigma/dtdM_x^2$	b-(GeV/c)$^{-2}$	$d^2\sigma/dtdM_x^2$	b-(GeV/c)$^{-2}$	$d^2\sigma/dtdM_x^2$	b-(GeV/c)$^{-2}$
5.5	0.700 ± 0.019	33.5 ± 2.4	0.635 ± 0.025	37.0 ± 3.3		
6.5	0.600 ± 0.010	34.7 ± 0.8	0.538 ± 0.010	32.6 ± 1.3	0.580 ± 0.057	25.1 ± 13.4
7.5	0.528 ± 0.013	30.4 ± 1.1	0.451 ± 0.009	34.0 ± 1.2	0.432 ± 0.010	37.3 ± 1.9
8.5	0.425 ± 0.011	32.9 ± 2.4	0.416 ± 0.015	35.1 ± 1.6	0.364 ± 0.008	32.0 ± 1.6
9.5	0.394 ± 0.007	33.0 ± 0.9	0.340 ± 0.011	35.3 ± 3.1	0.341 ± 0.005	34.6 ± 1.1
11.	0.335 ± 0.006	30.7 ± 1.0	0.307 ± 0.007	33.8 ± 1.0	0.293 ± 0.006	33.5 ± 1.0
13.	0.294 ± 0.010	31.5 ± 1.2	0.252 ± 0.015	33.1 ± 4.9	0.229 ± 0.004	32.8 ± 1.6
15.	0.243 ± 0.020	28.5 ± 2.9	0.217 ± 0.007	33.3 ± 2.9	0.214 ± 0.005	30.5 ± 1.1
17.			0.201 ± 0.005	34.3 ± 0.9	0.188 ± 0.005	31.3 ± 1.5
19.			0.177 ± 0.011	27.3 ± 8.2	0.167 ± 0.005	35.8 ± 2.8
22.			0.154 ± 0.005	31.9 ± 1.1	0.137 ± 0.003	34.8 ± 1.9
26.			0.126 ± 0.012	27.7 ± 4.5	0.125 ± 0.003	33.1 ± 1.4
30.					0.109 ± 0.004	33.1 ± 2.1
34.					0.101 ± 0.007	30.5 ± 1.8
38.					0.090 ± 0.020	28.9 ± 8.2

[a]Given in mb $(\mathrm{GeV}/c)^{-2}$ GeV^{-2}.

[b]See Eq. (4) in text.

where c was kept fixed at 62.3 $(\mathrm{GeV}/c)^{-4}$. This value was taken from the deuteron form factor[3] as determined in p-d elastic scattering.[2] The fit was made around the central value of our measured t range so that the best-fit values and errors of a and b remain uncorrelated. The lines in Fig. 1 are the best fits to the data using this formula.

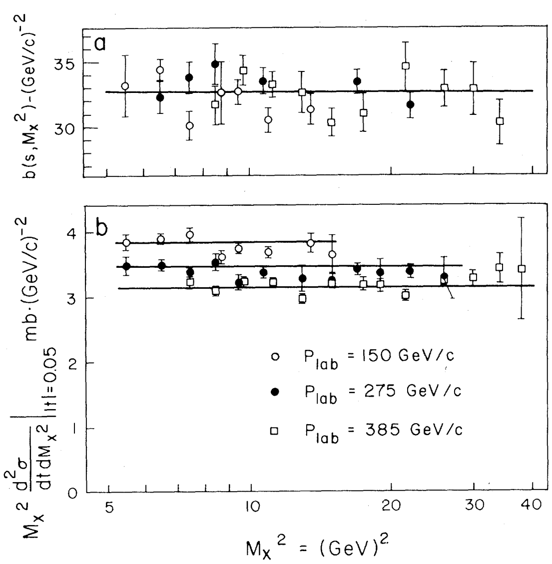

FIG. 2. Fitted values for $p+d\rightarrow X+d$ plotted versus M_X^2 for $p_{lab}=150$, 275, and 385 GeV/c. (a) The slope parameter $b(s,M_X^2)$ as obtained from the fit $d^2\sigma/dt\,dM_X^2\sim\exp[-b(s,M_X^2)|t|+62.3t^2]$. (b) Differential cross sections $d^2\sigma/dt\,dM_X^2$ at $|t|=0.05$ multiplied by M_X^2.

The results of the fits for $a(s,M_X^2)$ and $b(s,M_X^2)$ are given in Table I. In Fig. 2(a), we show $b(s,M_X^2)$ as a function of M_X^2. Within errors, it is independent of energy and of M_X^2. A one-parameter fit to all the $b(s,M_X^2)$ values yields $b=32.9\pm0.3$ $(\mathrm{GeV}/c)^{-2}$ with $\chi^2=1.33$ per degree of freedom. The values of $a(s,M_X^2)$ multiplied by M_X^2 are plotted in Fig. 2(b). It is apparent that $d^2\sigma/dt\,dM_X^2$ behaves predominantly as $1/M_X^2$. A fit of our data by the form

$$\frac{d^2\sigma}{dt\,dM_X^2}\bigg|_{|t|=0.05}=\frac{D(s)}{(M_X^2)^{\alpha(s)}} \tag{5}$$

yields the following results:

p_{lab}	$D(s)$	$\alpha(s)$	χ^2/d.f.
150	4.38 ± 0.33	1.068 ± 0.035	1.10
	3.784 ± 0.035	1	1.43
275	3.63 ± 0.17	1.028 ± 0.019	0.83
	3.391 ± 0.030	1	0.93
385	3.19 ± 0.15	1.004 ± 0.017	1.90
	3.157 ± 0.023	1	1.77

where p_{lab} is in GeV/c and $D(s)$ in mb $(\mathrm{GeV}/c)^{-2}$ GeV$^{2\alpha(s)-2}$, and d.f. means degrees of freedom. The values of $\alpha(s)$ obtained from the fit are consistent with unity. The values of $D(s)$ listed in the second row at each energy were obtained by setting $\alpha(s)=1$ in Eq. (5) and making a one-parameter fit. This simple $1/M_X^2$ fit is statistically acceptable and corresponds to the lines drawn in Fig. 2(b). It must be pointed out that the $1/M_X^2$ behavior for the cross section at fixed t does not hold if the M_X^2 range is extended to include the resonance region. This is illustrated in Fig. 3 where we have plotted our data together with the data[2] for $M_X^2<4$ GeV^2 for 275 GeV/c. The deviation of the low-mass data from the $1/M_X^2$ form is larger at the smaller t value.

The errors in $D(s)$, Eq. (5), do not include the normalization uncertainty of ± 3% mentioned previously. Taking this uncertainty into account, we have made a fit of all our data by the form

$$\left.\frac{d^2\sigma}{dt\,dM_X^2}\right|_{|t|=0.05}=A\left(1+\frac{B}{p_{\text{lab}}}\right)\frac{1}{M_X^2}. \tag{6}$$

We find $A=2.80\pm0.16$ mb $(\text{GeV}/c)^{-2}$ and $B=54\pm16$ (GeV/c) with $\chi^2=47$ for 35 degrees of freedom. The cross section at any t value in our range, obtained from (6) and (4) by use of the fitted slope $b=32.9\pm0.3$ $(\text{GeV}/c)^{-2}$, is given by

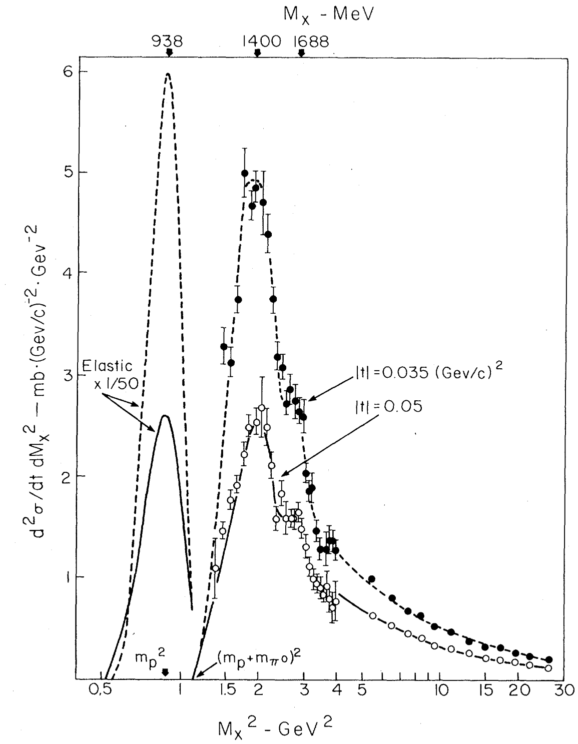

FIG. 3. Differential cross sections versus M_X^2 for $t=0.035$ and 0.05 for $p_{\text{lab}}=275$ GeV/c. Data for $M_X^2<4$ GeV^2 are from Ref. 2.

$$\frac{d^2\sigma}{dt\,dM_X^2}=\left[\frac{3.50\pm0.20}{M_X^2}\left(1+\frac{54\pm16}{p_{\text{lab}}}\right)e^{-(6.5\pm0.3)|t|}\right]F_d(t). \tag{7}$$

Here $F_d(t)$ is the coherence factor defined[2] as

$$F_d(t)=(\sigma_T^{pd}/\sigma_T^{pp})^2|S(t)|^2, \tag{8}$$

where σ_T is the total cross section and $S(t)$ is the deuteron form factor.[1] We have used $(\sigma_T^{pd}/\sigma_T^{pp})^2=3.6$ and[1] $|S(t)|^2=\exp(-26.4|t|+62.3t^2)$. In Eq. (7), we have purposely factorized the coherence factor in order for the term in the square brackets to represent the cross section for the diffraction dissociation of the proton per nucleon. As is the case with elastic scattering, the Glauber corrections are not expected to modify the slope of 6.5 ± 0.3 $(\text{GeV}/c)^{-2}$ by more than one unit. Our extracted nucleon-nucleon data for $M_X^2<4$ GeV^2 agree very well[2] with data from $p+p\to X+p$. A similar direct comparison for $M_X^2>5$ GeV^2 is not possible at present because of lack of experimental data for $p+p\to X+p$ at small values of t.

We are grateful to many members of the Fermilab staff and in particular to the personnel of the internal target section for their cooperation in the planning and execution of this experiment. We acknowledge the support of the technical staff at Rockefeller University and the University of Rochester. The Soviet members of our team express their gratitude to the U.S.S.R. State Committee for Atomic Energy and the Joint Institute for Nuclear Research, Dubna, for their generous support.

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[1]Y. Akimov et al., "Proton-Deuteron Elastic Scattering at Small Momentum Transfer from 50 to 400 GeV/c" (to be published).

[2]Y. Akimov et al., preceding Letter [Phys. Rev. Lett. 35, 763 (1975)].

[3]This is justified by the near factorization of the form factor in elastic scattering (Ref. 1) and by the factorization of the diffractive vertex in the low-mass region (Ref. 2). In a fit of our inelastic data where c was treated as a free parameter, we obtained $c = 64.3 \pm 11.4$ (GeV/c)$^{-4}$ in agreement with the (more accurate) value of 62.3 ± 1.1 given by the deuteron form factor.

Observation of a Difference between Polarization and Analyzing Power in Λ^0 Production with 6-GeV/c Polarized Protons*

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We have measured the polarization, analyzing power, and depolarization parameter for forward Λ^0's produced with a 6-GeV/c polarized-proton beam at the Argonne National Laboratory zero-gradient synchrotron. We collected a sample of 15 281 Λ^0 production events with subsequent $p\pi^-$ decays. There is a clear difference between the polarization and analyzing power for events with Feynman scaling variable x greater than 0.8. This is the first observation of this phenomenon at high energy.

Parity-conserving inclusive processes of the form spin $\frac{1}{2}$ (polarized) + unpolarized → spin $\frac{1}{2}$ (analyzed) + anything can be described[1] by observables which are a generalization of the Wolfenstein spin-rotation parameters for proton-proton elastic scattering.[2] The polarization $(P+P')$, the analyzing power $(P-P')$, the depolarization parameter (D), and the differential cross section σ are related as follows:

$$\sigma = \sigma_0[1 + (P - P')\vec{\mathfrak{e}} \cdot \hat{n}], \qquad (1)$$

$$\sigma \vec{\mathfrak{f}} \cdot \hat{n} = \sigma_0[(P + P') + D\vec{\mathfrak{e}} \cdot \hat{n}]. \qquad (2)$$

Here $\vec{\mathfrak{e}}$ is the initial (beam) polarization vector; $\vec{\mathfrak{f}}$ is the final (Λ^0) polarization vector; $\hat{n}$ is the production-plane unit normal (along $\vec{p}_{\text{beam}} \times \vec{p}_\Lambda$); and σ_0 is the cross section for unpolarized protons. $P+P'$ measures the component of the final state baryon polarization along the production plane normal that is produced independently of the beam polarization. $P-P'$ measures the left-right production asymmetry of the final-state baryon when the incident beam is vertically polarized. D measures the component of the beam polarization along the production-plane normal that is retained by the final-state baryon. For elastic scattering, time-reversal invariance constrains the polarization to be equal to the analyzing power. However, for inelastic processes like inclusive Λ^0 production the two parameters are not required to be equal.[3] Differences between polarization and analyzing power have previously been observed only in low-energy nuclear reactions.[4] We report here the first observation of this effect at high energy.

We have measured $P-P'$, $P+P'$, and D for Λ^0's produced in the forward direction by transversely polarized 6-GeV/c protons incident on a 20-cm liquid-hydrogen target. This experiment