It might be worth pointing out that the upper limits obtained in this search are of the order of 1% of the cross sections of similar strange-particle production processes at similar Q values.[5]

A number of other experimental searches for charmed-particle production are now in progress, but no results are available yet from any of them. The only previously published search[6] for charmed particles was sensitive only to longer-lived neutral states ("vees") produced in 400-GeV/c pp collisions and obtained upper limits on their production cross section one to two orders of magnitude larger than the results presented here.

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[1]J. D. Bjorken and S. L. Glashow, Phys. Lett. 11, 255 (1964).

[2]S. L. Glashow, J. Iliopoulos, and L. Maiani, Phys. Rev. D 2, 1285 (1970).

[3]A. De Rújula and S. L. Glashow, Phys. Rev. Lett. 34, 46 (1975), and other articles in the same issue.

[4]For experimental details, see M. Kalelkar, Ph.D. thesis, Columbia University (Nevis Report No. 207), 1975 (unpublished); S. Csorna, Ph.D. thesis, Columbia University, 1975 (unpublished).

[5]For example, in this experiment, the inclusive K^0 and Λ^0 production cross sections are ~ 2300 and ~ 850 μb, respectively.

[6]T. Ferbel, in *Experimental Meson Spectroscopy—1974*, AIP Conference Proceedings No. 21, edited by D. A. Garelick (American Institute of Physics, New York, 1974), p. 393

Cross Sections for "Diffractive" $p+p \to p+X$ from 100 to 400 GeV*

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We have measured the cross section for $p+p \to p+X$ for M_X^2 up to a constant fraction of s. We observe no rise for $130 < E < 400$ GeV. The inelastic cross section for $0 < M^2 < 0.06s$ is 2.50 ± 0.05 mb for various values of s from 263 to 752 GeV^2.

The recent observation at the CERN intersecting storage rings (ISR)[1] of the increase at high energy of the total cross section for proton-proton scattering has led to many speculations on the mechanism responsible for this rise. A candidate for such a mechanism is the so-called "diffractive process," $p+p \to p+X$, which shows an enhancement at low mass of X. For very low masses ($M^2 \sim 2$–3 GeV^2), this enhancement is known to have a constant cross section in the energy range from 30 to 300 GeV.[2,3] Triple Regge[4] phenomenology suggests a contribution to the low-M^2 spectrum of the form A/M^2. Integration of this contribution up to any constant fraction of the square of the total available energy s gives a cross section increasing as $A\ln(s)$. Since the total diffractive cross section has been variously measured[2,5] to be $2\times(1.7-2.6)$ mb, one might expect to observe a very large relative increase in this small cross section for the s range ~ 200 to ~ 800 GeV^2. We have performed an accurate measurement of the inelastic scattering cross section $d^2\sigma/dt\,dM^2$ for the reaction $p+p \to p+X$, covering the range of the square of the four-momentum transferred to the target proton $0.02 \lesssim -t \lesssim 0.22$ (GeV/c)^2, the range in invariant M^2 of X being $m_p^2 < M^2 < 0.13s$ and at values of the square of the center-of-mass energy $s = 244$ to 752 GeV^2.

We present here the results of our cross-section measurements. No rise with s is observed.

We have studied the reaction $p+p \to p+X$ at the internal target area of Fermilab by using the internal beam during both the acceleration cycle and the coasting time at the end of the acceleration. We identify and measure the low-energy recoil proton from the above reaction with solid-state detectors and we use polypropene (CH_3-CH-CH_2)$_n$ and carbon targets, obtaining the free-proton cross section by subtraction.[2,6] The overall arrangement consists of eight three-detector telescopes mounted on a carriage moving on a circular track centered on the beam-target interaction point. The distance from the first element to the interaction point is 85 cm. The solid-angle acceptance is defined by the 4×6 mm^2 sensitive area of a very thin first detector (150 μm). The half-angle acceptance in θ of each telescope is $\Delta\theta = 2$ mm/850 mm$\cong 0.13°$ and the angular separation between telescopes is $\sim 2.4°$. The whole array can be remotely positioned in the range 50° to 130° with an accuracy of 0.02°. The results reported here correspond typically to the angular range $83° > \theta > 57°$. In addition, a fixed telescope at $\sim 82°$ monitors the (beam)$\times$(hydrogen-in-target) luminosity by counting the elastic recoils. Typical rates are 4000 triggers/sec of which 2000 are identified as protons in the kinetic energy range $5 < T < 130$ MeV as well as deuterons and tritons from proton-carbon interactions. The event rate is kept constant by a servo which drives the target in and out of the beam rim. The target consists of a wheel carrying $(CH_2)_n$ and carbon fibers or foils covering $\sim 150°$ each. The wheel spins at ~ 65 Hz and an optical synchronization signal tells our data-collection system which target is in the beam. C and $(CH_2)_n$ data are thus simultaneously collected reducing many error sources. C and $(CH_2)_n$ data are normalized for subtraction by the total count of H_2 and H_3 fragments for each target accumulated for periods of approximately 20 min. The angular position of the array is changed every hour. The *average rate* is $\sim 10^6$ accepted events per hour. To increase our range in t, we accept protons crossing all three detectors. The second and third detectors are, respectively, 1000 and 5000 μm thick, corresponding to the range of 35-MeV protons.

A good measurement of the total energy lost in the two counters allows us to make a good separation of a crossing particle from background, and a measurement of the proton kinetic energy. The $(CH_2)_n$-C subtraction removes nonstopping d, t counted as protons. The correlation of the two energy-loss signals E_2 and E_3 is shown in Fig. 1. The enormously improved resolution as compared to other similar experiments[2,7] is mostly due to our development of new fast electronics and the use of an active collimator (the first counter).

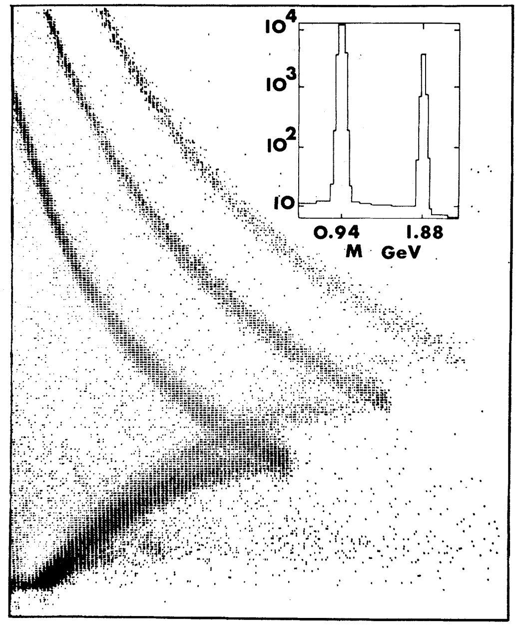

FIG. 1. Scatter plot of E_2 versus E_3 for $\sim 10^6$ ^{1}H, ^{2}H, ^{3}H recoils: π mesons are barely visible above the background. The inset shows the recoil mass separation for stopping ^{1}H and ^{2}H fragments.

Approximately 10^9 triggers were analyzed, equivalent to $\sim 5\times10^6$ free-proton events from a pure H_2 target. For conventional off-line analysis each event must have the following minimum information recorded: the two energies E_2 and E_3, the telescope number, the beam energy during which the event was detected, and the target type. From the two energies, the mass and kinetic energy are computed for each particle. Finally, the number of events versus T, i.e., dN/dT, is histogrammed independently for each telescope, beam energy, and target, as well as particle type. This procedure requires ~ 1 msec per event on a large computer and to process 10^9 events would have required months of computer time, making it impossible to obtain the fast-feedback information necessary for the successful performance of a parasitic experiment in the necessarily variable conditions at the internal target area. We therefore built a special-purpose digital computer which could perform all the above-mentioned operations on-line on each event. This computer includes a block of 40-nsec-cycle-time memory with 2000 8-bit words where functions are stored corresponding to the E_2 ver-

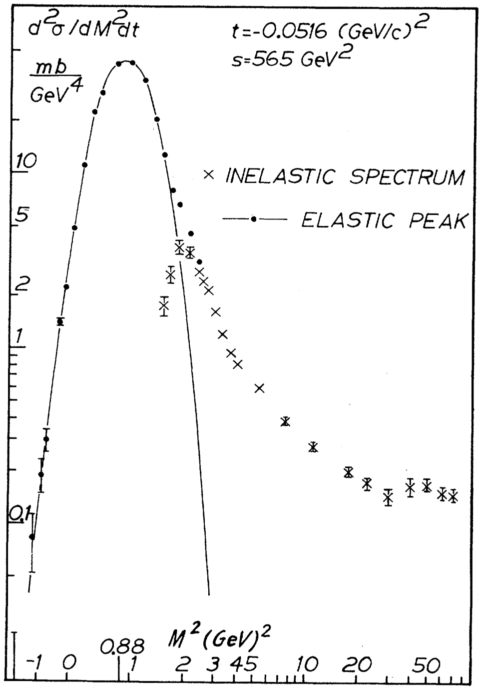

FIG. 2. An example of the measured differential cross sections.

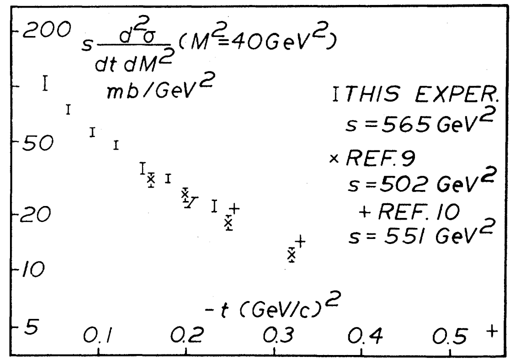

FIG. 3. Comparison of the invariant differential cross sections from various experiments.

sus E_3 correlation for the four cases of interest, plus the functions $T(E_3)$ and its derivative. Arithmetic operations are performed digitally on multiple paths. This "event analyzer" (the special-purpose computer) processes the most complicated case of a crossing particle within 200 nsec, hence reducing to zero any additional time necessary for event processing (~6 μsec are required for analog processing and the digital conversion of the detector signals). While running, we directly accumulate in the PDP-11 memory 256 histograms of dN/dT, 256 deuteron counts, and 256 triton counts [for the total number of (telescope) × (beam energy) × (target combinations)]. These distributions are typically written onto tape every 20 min. The event analyzer is the first sucessful application of modern digital electronic techniques to the on-line production of complete data distributions in a high-energy experiment.[8]

By moving each telescope to a series of known angles giving elastic recoil protons of known energies, we determine the T scale for each telescope. After the $(CH_2)_n$-C subtraction is performed and all data for the same [(telescope) × (energy) × (angle)] combination are added, $d^2N/dt\,dM^2$ is calculated. A typical result is shown in Fig. 2. The prominent peak at $M^2=m_p^2$ is due to elastic recoils. This peak falls by almost 5 decades on the low-M^2 side showing the absence of background. Figure 2 also shows how well the inelastic cross section can be separated from the elastic peak. Typically for $-t<0.1$, there is no elastic contribution in the measured cross section for $M^2>3$ GeV^2. We obtain slopes for elastic scattering of 11.3 ± 0.4 to 12.1 ± 0.3 for incident energies from 130 to 400 GeV which confirms our ability to measure t dependences. To convert the $d^2N/dt\,dM^2$ results to millibarn/GeV^4, we use $\sigma_{el}(0.023<-t<0.22\ (\text{GeV}/c)^2)=4.72$ mb independent of s. (We estimate a ±3% absolute scale error and a 2% energy-dependent uncertainty for this value.) The typical behavior of the inelastic M^2 spectrum is very similar at low t to our previous results.[2] The fall of the mass spectrum is much sharper than $1/M^2$ and typically has the form $a+c/M^\alpha$ with $\alpha=3$–4. At higher t, our previous result had a broad ripple at $M^2\approx10$ GeV^2 producing the anomalous t dependence shown in part of Fig. 3 of Ref. 1. This was mostly due to edge scattering in the collimators and poor resolution for crossing protons. These problems were eliminated in the present experiment and we have been able to measure up to $-t\lesssim0.22$ (GeV/c)^2 as compared to $-t\lesssim0.15$ (GeV/c)^2 previously. The t dependence from this experiment is consistent with exponential behavior with slopes $5<b<9$ (GeV/c)$^{-2}$ for the entire observed M^2 range, except for $2<M^2<3$, where we observe a slope of ~18. Our data for $d^2\sigma/dt\,dM^2$ are shown in Fig. 3 for values of t and M^2 overlapping the result of Abe *et al.*[9] and Albrow *et al.*[10] Figure 3 of Ref. 2 shows a flatter behavior. Note that the difference has little statistical significance.

Because of the t range covered in this experiment at all M^2 values, we are extremely insensi-

TABLE I. Cross section (mb) for $p+p \rightarrow p+X$ versus M^2 and s (GeV^2).

M^2 range	$s=263$[a]	319[a]	375[a]	565[a]	657[a]	712[a]	752[a]	197[b]	760[b]
$0-0.06s$	2.41	2.46	2.44	2.44	2.55	2.63	2.53		
	± 0.06[c]	0.06	0.06	0.06	0.09	0.07	0.09		
$0-0.1s$	3.20	3.14	3.10	3.11	3.03	3.04	3.09	3.40	3.30
	± 0.07[c]	0.07	0.07	0.07	0.10	0.08	0.10	0.35	0.30

[a]This experiment.

[b]Ref. 12.

[c]The quoted error does not include a $\pm 1\%$ energy-dependent uncertainty due to the absolute normalization and a -3% to $+10\%$ energy-independent uncertainty due to the t integration; see text.

tive to the actual value of the slope parameter in performing a t integration. We estimate that $(63.4 \pm 3)\%$ of the cross section is included in our t range for $b = 7 \pm 2$. This fraction could decrease by as much as 10% if $d\sigma/dt$ were to flatten out at large $|t|$. Both uncertainties are energy independent. We give in Table I the total inelastic cross section up to $0.06s$ and $0.01s$ for seven values of s. The two values, $0.06s$ and $0.1s$, were chosen, respectively, to include most of the low-mass enhancement and most of our measured range. Chapman *et al.*[12] have reported results for σ $(0.9<x<1)$ at 100 and 400 GeV obtained in a bubble chamber. This x range is equivalent to $M^2 < 0.1s$. We obtain excellent agreement with these results. Akimov *et al.*[7] have reported (from a $p+d \rightarrow d+X$ experiment) that $d\sigma(pp \rightarrow pX)/dM^2 \cong 0.7/M^2$ independent of s. Integration of this formula to any constant fraction of s gives an increase in σ of 0.74 mb from 139 to 400 GeV. Our data for the "diffractive" cross section can accomodate a 4% rise corresponding to the same fractional rise in σ_{tot}, but it is far from showing enough rise to account for the whole observed effect in the total cross section. The new Fermilab data[11] and the ISR data[1] give a 1.7 mb change from 200 to 400 GeV, corresponding to a 0.85 mb change in any of our presented measurements for the diffractive beam dissociation cross section if the whole change in the total cross section were due to the low-M^2 enhancement of $pp \rightarrow pX$. The results presented are strictly experimental and do not depend on assumptions about the M^2 spectrum shape.

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[1]U. Amaldi *et al.*, Phys. Lett. 44B, 112 (1973); S. R. Amendolia *et al.*, Phys. Lett. 44B, 119 (1973).

[2]S. Childress *et al.*, Phys. Rev. Lett. 32, 389 (1974); V. Bartenev *et al.*, Phys. Lett. 51B, 299 (1975).

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

[4]A. Capella *et al.*, Phys. Rev. Lett. 31, 497 (1973).

[5]J. Whitmore, Phys. Rep. 10C, 273 (1974).

[6]J. Lee-Franzini *et al.*, in *Proceedings of the International Conference on Instrumentation for High Energy Physics, Frascati, Italy, 1973,* edited by S. Stipcich (Laboratori Nazionali del Comitato Nazionale per l'Energia Nucleare, Frascati, Italy, 1973).

[7]Y. Akimov *et al.*, contributed paper to the Seventeenth International Conference on High Energy Physics, London, England, 1974, and NAL Report No. NAL-Conf. 74/56-Exp (to be published). See also F. K. Loebinger, 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).

[8]P. Franzini, in SLAC Report No. SLAC 179, 1974, Proceedings of the Summer Institute on Particle Physics, Stanford, California, 1974 (unpublished), Vol. II, p. 159.

[9]K. Abe *et al.*, Phys. Rev. Lett. 31, 1527 (1973).

[10]M. G. Albrow *et al.*, Nucl. Phys. B54, 6 (1973).

[11]A. S. Carroll *et al.*, Phys. Rev. Lett. 33, 928 (1974).

[12]J. W. Chapman *et al.*, Phys. Rev. Lett. 32, 257 (1974).