[1]R. Jackiw and C. Rebbi, Phys. Rev. Lett. 36, 1116 (1976).
[2]P. Hasenfratz and G. 't Hooft, Phys. Rev. Lett. 36, 1119 (1976).
[3]See, e.g., G. Wentzel, *Quantum Theory of Fields* (Interscience, New York, 1949), Appendix I, where the significance of this tensor is also explained.
[4]H. B. Nielsen and P. Olesen, Nucl. Phys. B61, 45 (1973).
[5]G. 't Hooft, Nucl. Phys. B79, 276 (1974).
[6]A. M. Polyakov, Pis'ma Zh. Eksp. Teor. Fiz. 20, 430 (1974) [JETP Lett. 20, 194 (1974)].

Comparison of the Shapes of π^+p and pp Diffraction Peaks from 50 to 175 GeV/c*

Fermilab Single Arm Spectrometer Group†
Fermi National Accelerator Laboratory, Batavia, Illinois 60510
(Received 4 May 1976)

The ratio of π^+p to pp elastic scattering is found to be smoothly varying over the range $-t=0.03$ to 0.4 GeV^2. It is well fitted by a single exponential, indicating the forward behavior must be quite similar for the two reactions.

It has been known for some time that the logarithmic slope for pp elastic scattering is steeper at small momentum transfers, $-t \lesssim 0.15$ GeV^2, than at larger momentum transfers.[1] Although some increase at small t is expected on the basis of quadratic fits of the type

$$d\sigma/dt = Ae^{Bt+Ct^2},$$

a high statistics experiment[2] at the CERN intersecting storage rings indicated a break, or more rapid change in slope, near $-t=0.15$ GeV^2 of about 1.5 GeV^{-2}. At Fermilab energies a comparison of the slopes observed in the gas jet experiment[3] in the range $0.005 \leq -t \leq 0.09$ GeV^2 with our[4] and other[5] results at an effective $-t=0.2$ GeV^2 gives a slope change of about 1.3 GeV^{-2}. This can be compared with a change of 0.8 GeV^{-2} expected on the basis of the quadratic fits to the spectrometer data, where typically $C=2$ and is positive.

To further investigate the small-t behavior of the π^+p and pp elastic scattering, systematic errors must be reduced to a minimum. To this end, we have examined the ratio

$$R = \frac{d\sigma(\pi^+p \to \pi^+p)/dt}{d\sigma(pp \to pp)/dt}$$

in the region $-t \leq 0.4$ GeV^2. Since the π^+p and pp data were taken simultaneously, this ratio is insensitive to many systematic effects and gives a highly reliable result on the relative behavior of the two processes.

The experiment used the Fermilab $M6E$ high precision beam line and the Single Arm Spectrometer Facility to detect scattered particles. Proton and π^+ scattering off hydrogen were measured simultaneously under identical conditions using the same acceptance and detectors. The apparatus has been previously described[4] and we will only discuss those features germane to the π^+/p ratio.

The beam line contained scintillation hodoscopes to tag the incoming momenta and angles. Pions were identified with a threshold gas Cherenkov counter, while protons were identified with a gas differential counter, and kaons with a DISC counter. A pion trigger required both that the threshold counter fired and that no proton or kaon accompanied the pion. A proton trigger required a proton coincidence and no accompanying pion or kaon. The elastic scattering angle was varied by changing the angle of incidence of the beam on the target, the t range being covered in a series of steps. No Cherenkov information was used in the trigger requirement for particles scattered into the spectrometer, leaving the trigger equally efficient for protons and pions aside from losses of pions from decays. To check that the beam line trigger requirements introduced no systematic biases, a sample of beam triggers was simultaneously recorded along with the beam spectrometer events. The phase space distribution of these beam triggers could be determined from the hodoscope information and was essentially the same for pions and protons.

Several potential sources of error were considered. The momentum resolution ($\sim 0.1\%$) was sufficient for the elastic scattering peak to be almost completely separated from the inelastic processes with at most a few percent contamina-

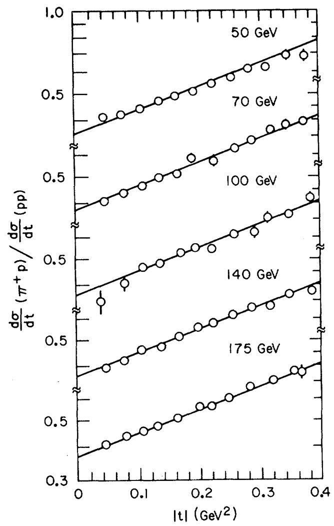

FIG. 1. The ratios R of the cross sections of elastic π^+p scattering to elastic pp scattering plotted versus $-t$ at energies of 50, 70, 100, 140, and 175 GeV. The lines drawn in have the form $\exp(-1.9t)$ and are for comparison purposes only (see Table I for the fits).

tion. Since the inelastic cross sections in the neighborhood of the elastic peak scale proportionally to the elastic cross sections,[6] the effects of this contamination cancel in the ratio. Another source of potential error arose from possible changes in the μ and e contaminations in the beam. This small contamination was misidentified as pions by the Cherenkov trigger requirement and could thus cause a variation in the pion cross section. The contamination, which was checked periodically, amounted to a few percent and remained constant to better than 1%. A possible source of error came from two beam particles separated in time by less than the resolving time of the electronics (same rf bucket). This was largely eliminated by the requirements of "one particle only" in the beam hodoscopes and at most 1% of the triggers contained two particles. Radiative and target-empty corrections were made and amounted to at most 10%. Estimates were made for Coulomb interference effects and were never more than 3%. Corrections of a few percent were made to the ratios to take into account double-scattering pion bremsstrahlung, pion decay, and target attenuation. These corrections are small ($\lesssim 4\%$) and only slowly varying in t. Accordingly, we believe the systematic errors affecting the t dependence of cross section ratios were less than 1.5%.

Figure 1 shows plots of the ratios of π^+p to pp scattering at each energy. It is clear from visual inspection that a simple exponential fit provides an excellent representation of the data. The use of more complex fitting functions does not significantly improve the quality of the fits. The results of fitting to various t ranges are shown in Table I.

Figure 2 compares the exponential slopes found at small $-t$ (0.03 to 0.125 GeV^2) with those at larger $-t$ (0.125 to 0.40 GeV^2). Although the small $-t$ slope has considerable statistical uncertainty and some fluctuations, the two slopes agree with one another to within ± 0.25 GeV^{-2} when averaged over momentum. Given this result and the smoothness of the π^+/p ratios, we conclude that structure, if any, must be quite similar for the two reactions in this t region.[7]

We would like to express our thanks to the many people at Fermi National Accelerator who have contributed to the successful operation of the single arm spectrometer and of the accelerator and beam lines. We would also like to express appreciation to our technical support personnel for

TABLE I. Results of the fit of the elastic cross section ratios $R = d\sigma/dt(\pi^+p)\,(d\sigma/dt)^{-1}(pp)$ to the single exponential form $R = Ae^{-bt}$ for the t ranges indicated in GeV^2.

E (GeV)	$b(0.03-0.4)$ (GeV^{-2})	$b(0.03-0.125)$ (GeV^{-2})	$b(0.125-0.4)$ (GeV^{-2})
50	1.52 ± 0.06	1.00 ± 0.24	1.56 ± 0.10
70	1.97 ± 0.06	1.91 ± 0.39	1.96 ± 0.10
100	1.94 ± 0.12	(a)	1.93 ± 0.14
140	1.91 ± 0.05	2.56 ± 0.41	1.86 ± 0.08
175	2.00 ± 0.05	1.89 ± 0.29	2.05 ± 0.08

[a] Only a small amount of data were available at 100 GeV in the small t range.

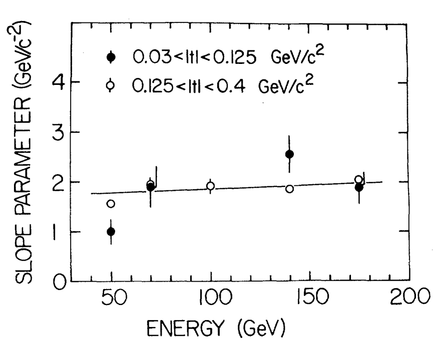

FIG. 2. Values of the slope parameter for the ratio R for the t ranges 0.03 to 0.125 and 0.125 to 0.4 (GeV/c)^2 versus the beam energy. (The line is simply to guide the eye and is not the result of a fit).

their invaluable assistance.

*Work supported in part by the U. S. Energy Research and Development Administration, the National Science Foundation, and Istituto Nazionale di Fisica Nucleare (Italy).

†D. S. Ayres, R. Diebold, and G. J. Maclay, Argonne National Laboratory, Argonne, Ill. 60439, and D. Cutts, R. E. Lanou, L. J. Levinson, and J. T. Massimo, Brown University, Providence, R. I. 02912, and J. Litt, CERN, Geneva, Switzerland, and Daresbury Nuclear Physics Laboratory, Daresbury, Lancashire, England, and R. Meunier, CERN, Geneva, Switzerland, and Centre d'Etudes Nucléaires de Saclay, 91 Gif-sur-Yvette, France, and M. Sogard, Enrico Fermi Institute, University of Chicago, Chicago, Ill. 60637, and B. Gittelman, Cornell University, Ithaca, N. Y. 14850, and A. E. Brenner, J. E. Elias, and G. Mikenberg, Fermi National Accelerator Laboratory, Batavia, Ill. 60510, and L. Guerriero, P. Lavopa, G. Maggi, C. DeMarzo, F. Posa, G. Selvaggi, P. Spinelli, F. Waldner, and E. F. Anelli, Università di Bari, Bari, Italy, and Istituto Nazionale de Fisica Nucleare, Sezione di Bara, Italy, and 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, Mass. 02139, and B. Gottschalk, Northeastern University, Boston, Mass. 02115, and R. L. Anderson, D. Gustavson, K. Rich, D. M. Ritson, and G. A. Weitsch, Stanford Linear Accelerator Center, Stanford, Cal. 94305, and E. C. Loh, University of Utah, Salt Lake City, Utah 84112.

[1]R. A. Carrigan, Jr., Phys. Rev. Lett. 24, 168 (1970).

[2]G. Barbiellini *et al.*, Phys. Lett. 39B, 663 (1972).

[3]V. Bartenev *et al.*, Phys. Rev. Lett. 31, 1088 (1973).

[4]Fermilab Single Arm Spectrometer Group, Phys. Rev. Lett. 35, 1195 (1975).

[5]C. Akerlof *et al.*, Phys. Rev. Lett. 35, 1406 (1975).

[6]Fermilab Single Arm Spectrometer Group results on inelastic diffractive scattering (to be published).

[7]In a separate analysis of the π^+p, π^-p, and pp elastic data from this experiment, it was found that at 50 and 70 GeV/c the forward slopes of these processes increase by typically 0.3 ± 0.2 GeV^{-2} over that given by a quadratic fit to the data at $-t>0.12$ GeV^2.

Comment on the Deuteron Structure Function $A(q^2)$ at High Momentum Transfers

Werner Fabian* and Hartmut Arenhövel
Institut für Kernphysik, Universität Mainz, D-6500-Mainz, Germany
(Received 15 June 1976)

Calculations of $A(q^2)$ were performed for various *NN* potentials and electromagnetic nucleon form factors at $q^2=0-160$ fm^{-2} with inclusion of isobar configurations and meson exchange currents, indicating that recent elastic electron scattering experiments do *not* rule out the existence of isobar configurations and meson exchange currents in the deuteron as has been conjectured.

Recent experiments[1] on elastic electron scattering from deuterium for momentum transfers up to $q^2=6$ (GeV/c)^2 have considerably increased our knowledge of the electromagnetic structure of the deuteron in the high momentum region. In these experiments essentially the structure function $A(q^2)$ was measured. In comparison with theoretical predictions it was found that the impulse approximation using nonrelativistic deuteron wave functions gives quite a good description of the data, while some predictions on meson exchange current (MEC) contributions[2,3] seemed to be in complete disagreement. In the meantime it has been emphasized that the contributions from MEC are consistent with the data if proper form factors are included.[4]

In addition the authors of Ref. 1 conclude that isobar admixtures in the deuteron—to the extent that they give significant high-momentum components to the deuteron wave function that would flatten out $A(q^2)$—are made highly improbable by this experiment. It is the purpose of this Comment to point out that as far as the lowest isobar configurations (IC) in the deuteron—essentially the $\Delta\Delta(1236)$ component—are concerned they do not allow such a conclusion. In fact, the contributions from IC are small and of the same order of magnitude as uncertainties introduced by different nucleon form-factor fits.

Therefore, we have extended our previous calculation[5] of $A(q^2)$ for momentum transfers up to $q^2=160$ fm^{-2} including IC and lowest order isoscalar MEC using a variety of different *NN* potentials, IC transition potentials, and nucleon form factors. We have evaluated $A(q^2)$ as described earlier.[5,6] For the IC calculations, the $\Delta\Delta(1236)$ and $NN'(1470)$ channels were included in the deuteron wave function. The isobar chan-