A similar comparison can be made with π^0 photoproduction from protons and neutrons. But given only $\pi^0 p$ without $\pi^0 n$ data one must make assumptions about the interference of the isoscalar and isovector photon amplitudes. We have attempted such a comparison with our data; the results are inconclusive. However the large π^0 asymmetry ($\alpha \cong 1.0$) and thereby the large $d\sigma_\perp$ for π^0 photoproduction suggest similar difficulties for the vector-dominance model.

The authors wish to thank J. Thebado of the Cambridge Electron Accelerator for his help in bringing the crystal goniometer into operation and the operating crew of the accelerator, under H. Winick, for their necessary help. The authors wish to express their sorrow at the death of our young colleague, Riley Bordelon, whose enthusiasm, good humor, and energy contributed greatly to the initial stages of this experiment.

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STRUCTURE IN NEUTRON-PROTON CHARGE EXCHANGE*

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Neutron-proton charge-exchange differential cross sections for incident-neutron momenta between 600 and 2000 MeV/c show a sharp change in the slope of $d\sigma/dt$ vs $-u$ in the vicinity of $-u = 0.01$ (GeV/c)^2. Near the one-pion threshold the slope at $u = 0$ shows a maximum which reaches a value of order 100 (GeV/c)$^{-2}$. Also presented, as a function of s, is the intercept at $u = 0$ which shows a pronounced deviation from smoothness in the region above the inelastic threshold.

Differential cross sections for neutron-proton charge exchange,

$$np \to pn,$$

have been measured for incident-neutron momenta between 600 and 2000 MeV/c. The data near $u = 0$ [1] presented here are a portion of a larger work[2,3] and exhibit several significant features of nucleon-nucleon scattering. They show a sharp change in the slope of $d\sigma/dt$ vs $-u = 0.01$ (GeV/c)^2. The slope of $d\sigma/dt$ at $u = 0$, as a function of s, shows a maximum in the region near the one-pion threshold. Also presented is $d\sigma/dt$ at $u = 0$ as a function of s using the absolute normalization determined during the experiment. Our points between 750 and 1250 MeV/c show a pronounced departure from a smooth curve joining data at lower and higher momenta.

The experiment was performed at the 3-GeV Princeton-Pennsylvania Accelerator using neutrons produced at 34° with respect to the internal proton beam. The incident-neutron momentum was determined by measuring the time of flight over a 108-ft flight path. The technique used the rf structure of the beam spill and had a resolution better than 2 nsec.[4] The neutrons were scattered in a thin-walled liquid-hydrogen target, and the recoil protons were detected in a wire-spark-chamber magnetic spectrometer. The complete data set, including laboratory angles up to 60°, contains over 500 000 elastic events.

The spectrometer consisted of four wire-chamber gaps on each side of an analyzing magnet. The gaps had magnetostrictive readout and were read into an on-line computer.[5] Data were taken with the spectrometer at 17° and 43° with respect to the neutron beam and with both polarities of the magnetic field. The various configurations covered four partially overlapping ranges of proton angles. In the forward position the beam went through the spectrometer, thus 180° (c.m.) elastic scattering could be detected.

The momentum and scattering angles for each event were calculated by first fitting a straight line to the sparks in the front and rear chambers independently and then evaluating at the target the parameters of a trajectory fitted to the two straight lines. The momentum of each event was corrected for ionization losses in the hydrogen target and spectrometer material.

The three-momentum of the charged particle was combined with the momentum of the incident neutron to compute the invariant mass of the undetected recoiling system. Those events corresponding to the process $np \to np$ were easily selected since, if the charged particle were assumed to be a proton, only elastic np scatters could give a missing mass as low as the neutron mass.

After the data were sorted by incident momentum and laboratory scattering angle into bins missing-mass histograms were made. From these, elastic events could be selected and backgrounds subtracted. At high momenta the background arose from inelastic contamination resulting from decreasing resolution. It varied from 0 % at 1200- to 6 % at 2000-MeV/c incident momentum. At low momenta a different kind of background occurred due to ambiguity involved in distinguishing high-momentum inelastic scattering from low-momentum elastic scattering.[6] The required subtraction varied from 7 % at 600 to 0 % at 760 MeV/c.

The geometric efficiency of the spectrometer was determined directly from the data and by a Monte Carlo program for each momentum and polar scattering angle. The two independent methods agreed at the 1% level. The geometric efficiency was 100 % for forward-going protons within 3° of the beam direction.

The spark-chamber efficiency was calculated from 3- and 4-spark events for each square inch of each chamber. Each event was appropriately weighted for this efficiency. The overall efficiency was greater than 98 % for more than 90 % of the events used. Any point in the cross sections which was corrected by more than 25 % was discarded.

Appropriate cuts were made on the data to define the spectrometer aperture and the target volume. For the forward angles a measured target-empty subtraction of 1 % was made instead of a target cut. Cuts to eliminate events with large χ^2 values for the fits affected the data at the 1% level.

In order to determine the absolute normalization of the cross sections the efficiency of a neutron counter was measured as a function of neutron momentum during the experiment by detecting scattered neutrons in coincidence with the proton spectrometer. The counter was then placed in the incident-neutron beam to determine the absolute flux as a function of momentum. Uncertainties in the normalization varied between 3 and 10 %.

A correction was made for the relative normalization of the data taken with different spectrometer positions and magnet polarities. The range-to-range discrepancy affected only the data above 1000 MeV/c, and no correction was necessary for data with $|u| < 0.04$ (GeV/c)^2. The effect correlates with magnet polarity and is consistent with an efficiency loss in a spectrometer counter due to the fringing field. A number of independent cross checks verified the magnitude and direction of the correction.

Figure 1 presents $d\sigma/dt$ vs $-u$ near $u = 0$ for representative momenta of the 16 available. The position of the break in the slope and the steepness of the initial slope change with momentum. Beyond the break the slope is independent of momentum and is ≈6.5 (GeV/c)$^{-2}$. Gaps in the data are the result of nonoverlapping spectrometer acceptance angles at low momenta.

In Fig. 2(a) the logarithmic slope β defined by the equation

$$d\sigma/dt = e^{\beta u}(d\sigma/dt)_{u=0}, \quad 0 < |u| < |u_{\text{break}}|,$$

is plotted versus $s - 4M^2$, where M is the nucleon mass. We use $s - 4M^2$ in order to avoid crowding at low momenta. In most cases the choice of u_{break} was clear, and ambiguities were resolved by χ^2 tests. The distribution of χ^2 probabilities for the fits is acceptable.

Our data show that the slope reaches a maximum of approximately 100 (GeV/c)$^{-2}$ in the region of the one-pion threshold. The values of β computed from other experiments[7-11] are included in Fig. 2(a). Most have adequate data in the fitted region, and they are generally consistent

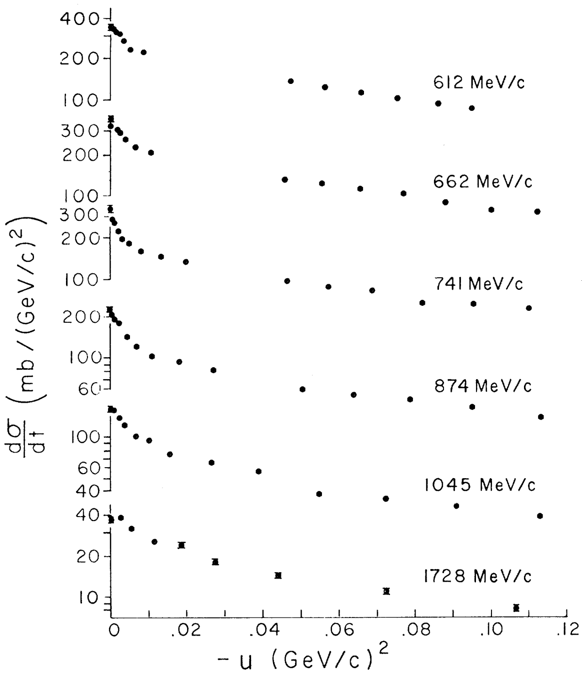

FIG. 1. Plots of the n-p charge-exchange differential cross section $d\sigma/dt$ vs $-u$ near $u=0$ for selected momenta in our experiment.

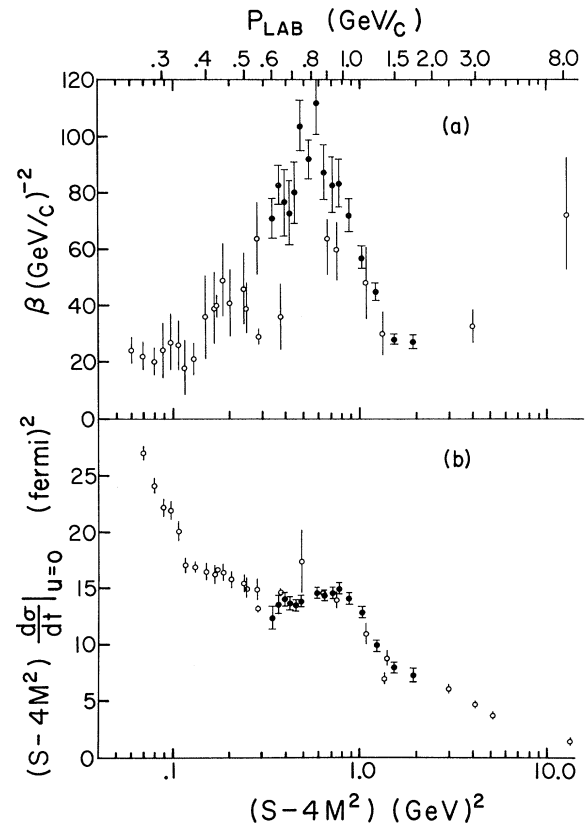

FIG. 2. (a) A plot of the logarithmic slope

$$\frac{d}{dt}\ln\left(\frac{d\sigma}{dt}\right)_{u=0}=\beta$$

as a function of $s-4M^2$. (b) A plot of the intercept $(s-4M^2)(d\sigma/dt)_{u=0}$ as a function of $s-4M^2$. The black dots are data from this experiment and the open circles were computed from the data of Refs. 7-12.

with our data.

The behavior of the intercept $d\sigma/dt$ at $u=0$ as a function of s is presented in Fig. 2(b). We have multiplied the intercept by the quantity $s-4M^2$ in order to compensate for the rapid variation of the cross section with s. Above the one-pion threshold the figure shows a deviation from a smoothly falling curve joining data[7-12] above and below the range covered by our experiment. At low momenta, the normalization of other experiments is well-determined from the total cross section. Despite the problem of normalization above the inelastic threshold, other experiments agree well with ours. We emphasize that our normalization was determined completely from our own measurements. Further, we note that the range-to-range normalization problems mentioned above were not involved in the data points used to compute the parameters presented in Fig. 2.

We point out that the slope and the intercept are relatively independent experimentally. For instance, a peculiar normalization error could give rise to the behavior in Fig. 2(b), but the slope is independent of normalization. On the other hand, an error in the geometric efficiency could distort the slope, but the points nearest 180° (c.m.) which fix the intercept at $u=0$ are 100% efficient and independent of the geometric-efficiency calculations.

We mention an independent check on the validity of these data. A companion experiment,[3] which used the same spectrometer and beam line, measured pp elastic scattering in the same momentum range. The resultant cross sections agree in shape and magnitude with other data, where they are available.

We have considered several possibilities to explain the structure described above including threshold effects, a two-baryon particle or resonant state,[13] and the influence of t-channel resonances on the backscattering cross section. We do not have enough evidence to draw firm conclusions at the present time, but further analysis and other data from both experiments will be presented later.

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HARMONIC-OSCILLATOR ANALOGY FOR THE VENEZIANO MODEL*

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A model for particle scattering amplitudes is based on the harmonic-oscillator Green's function. The model is Regge behaved, and in first approximation is a zero-width theory. The derived amplitudes are very similar to Veneziano n-point functions although they lack duality.

We present a model scattering matrix based on a relativistic harmonic oscillator. The interest in the model stems from its similarity to the Veneziano model in the following respects: (i) It contains an infinite spin-mass spectrum identical to the Veneziano model. However, it should be remarked that the degeneracy at each daughter site is probably different. (ii) The lowest order of perturbation theory is a zero-width approximation. (iii) The model is multi-Regge behaved. (iv) By appropriate choice of a single parameter the coupling scheme of the leading trajectory is identical to that in the Veneziano model. (v) The Chan[1] representation for the n-point function is modified in a remarkably simple manner in the oscillator model.

Questions of renormalization, finite-width corrections, off-shell continuations, and local currents in the model are under investigation by Frye, Gallardo, and the author.

Consider the Bethe-Salpeter equation for a quark-antiquark pair,

$$(\Box_1 - m^2)(\Box_2 - m^2)\psi(x_1, x_2) = U(x_1, x_2)\psi. \tag{1}$$

Letting $m^2 \to \infty$ so that $U/m^2 - m^2$ remains finite and making a change of variables to $X = \frac{1}{2}(x_1 + x_2)$ and $x = (x_1 - x_2)$ gives

$$[\tfrac{1}{2}\Box_X + 2\Box_x + V(x)]\psi(x, X) = 0. \tag{2}$$

A solution with total four-momentum p has the form $e^{ipX}\varphi(x)$. Inserting this in Eq. (2) and performing a Wick rotation gives the O(4)-symmetric