The relativistic form of the latter is [$*\omega_{12} = \omega_{03}$, etc]

$$\mathcal{L}_{\omega\rho\pi} = (g/m_\rho)(*\omega^{\mu\nu}\rho_\nu + *\rho^{\mu\nu}\omega_\nu)\cdot\pi_\mu.$$

We present two electromagnetic tests of this prediction. The substitution $\rho_\nu^{(0)} \to (e/g)A_\nu$ gives, effectively,

$$\mathcal{L}_{\omega\gamma\pi} = -(e/m_\rho)*\omega^{\mu\nu}F_{\mu\nu}\pi^{(0)},$$

and the width anticipated for the decay $\omega \to \gamma + \pi$ is 0.96 MeV. The present experimental value is 1.2 ± 0.2 MeV. The further electromagnetic substitution, $*\omega^{\mu\nu} \to \frac{1}{3}(e/g)(m_\rho/m_\omega)*F^{\mu\nu}$, produces

$$\mathcal{L}_{\gamma\gamma\pi} = -\tfrac{1}{3}(e^2/g)(1/m_\omega)*F^{\mu\nu}F_{\mu\nu}\pi^{(0)}.$$

The width predicted for $\pi^0 \to \gamma + \gamma$ is 7.4 eV. The measured value is 7.4 ± 1.5 eV.

*Publication assisted by the U. S. Air Force Office of Scientific Research.

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[4]Except in a rest frame of the particles. But such a rest frame is useless for the discussion of γ_5 transformations.

[5]To completely realize $U(4) \otimes U(4)$ transformations, other field components are required which would make asertions about η and η^* couplings, for example, but we shall not write them out.

[6]It suffices to consider the proton state with $S_z = \frac{1}{2}$ and to represent it unsymmetrically by $\Psi_{\sigma_1+,\sigma_2+,\sigma_3-}$, where the first two spins are in a triplet state. Then $\langle\sum_\alpha \sigma_\alpha^z \tau_\alpha^3\rangle = (\vec{S}_{12} - \vec{S}_3)\cdot\vec{S}/\frac{3}{4} = 5/3$, since $\vec{S}_{12}\cdot\vec{S} = 1$ and $\vec{S}_3\cdot\vec{S} = -\frac{1}{4}$.

[7]The classic SU(6) value for $-G_A/G_V$ is 5/3. The same result is obtained from current-commutator matrix elements that are restricted to the baryon octuplet and decuplet. This has produced much discussion of more elaborate mixing schemes. The new situation seems to reflect the different physical interpretation given to chiral transformations. Such a transformation on N generates $N+\pi$, not N and N^* with orbital motion.

[8]Whenever confusion of indices may occur, (0) is used to designate neutral particles.

MEASUREMENTS OF π^0 PHOTOPRODUCTION CROSS SECTIONS FOR INCIDENT GAMMA-RAY ENERGIES OF 2.0 TO 5.0 GeV*

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(Received 10 April 1967)

Cross sections for the reaction $\gamma + p \to \pi^0 + p$ for incident gamma-ray energies of 2.0 to 5.0 GeV and for baryon four-momentum transfers squared of 0.5 to 4.0 $(\mathrm{GeV}/c)^2$ are presented. The results are compared with theoretical predictions based on Reggeized vector-meson exchange.

We report here measurements of the differential cross section for the reaction $\gamma + p \to \pi^0 + p$ over a wide range of incident photon energies (2.0 to 5.0 GeV) and of baryon four-momentum transfers squared [0.5 to 4.0 $(\mathrm{GeV}/c)^2$]. Since the experimental method, along with earlier cross-section results, are reported in detail elsewhere,[1-3] we give below only a brief description of the experimental technique.

The experiment was performed using the bremsstrahlung beam from the Cambridge Electron Accelerator. The momenta and angles of the recoil protons were measured with a magnetic-spectrometer system that used scintillation counters and scintillation-counter hodoscopes as detectors. The π^0-decay gammas were detected in a 6×8 array of lead-glass shower counters that measured both the laboratory angles and the energies of the detected gammas. Background events due to reactions such as $\gamma + p \to \pi^0 + \pi^0 + p$ were separated from $\pi^0 p$ events by requiring that the energies and angles of the detected π^0-decay gammas be consistent with the energy and angles of the parent π^0, predicted from the measured proton kinematics. In making these predictions we assumed that each proton was produced in association with a single π^0. For events in which both π^0 gamma rays were detected, the gamma-hodoscope information gave five kinematic constraints that each event had to satisfy if the event was to be accepted as an elastically produced π^0. For events in which only one π^0 gamma was detected, one kinematic constraint was available. After applying these kinematic criteria, the events selected as elastic π^0's had a contamination of inelastic events of less than 10%, typically.

Our measurements, along with earlier Massachusetts Institute of Technology data[1,2] and data from the Bonn group,[4] are shown in Fig. 1(a) where we plot $d\sigma/dt$ vs $-t$ for several incident photon energies. In this figure the dash-dot lines are smooth curves drawn through the existing data points and the dotted lines are interpolations, $E_\gamma = 2.5$ GeV, and extrapolations, $E_\gamma > 3.0$ GeV, of the Bonn data. The dashed lines are the theoretical calculations of Locher and Rollnik[5] which are discussed at the end of this paper. For both Figs. 1(a) and 1(b) the error bars plotted with each of our data points include the following uncertainties: statistical, lack of knowledge of the exact distribution of background events in the region of the kinematic peaks associated with elastic events (~±10%), and uncertainties in the π^0 detection efficiencies (~±10%). In addition, the uncertainties in hydrogen target thickness, spectrometer acceptance, nuclear-absorption correction, counter efficiencies, and beam monitoring result in an error of ±16% which affects each point equally. This uncertainty is not included in the plotted error bars.

The behavior of the cross sections as a function of $|t|$ is similar to that observed in meson-nucleon scattering and in other photoproduction

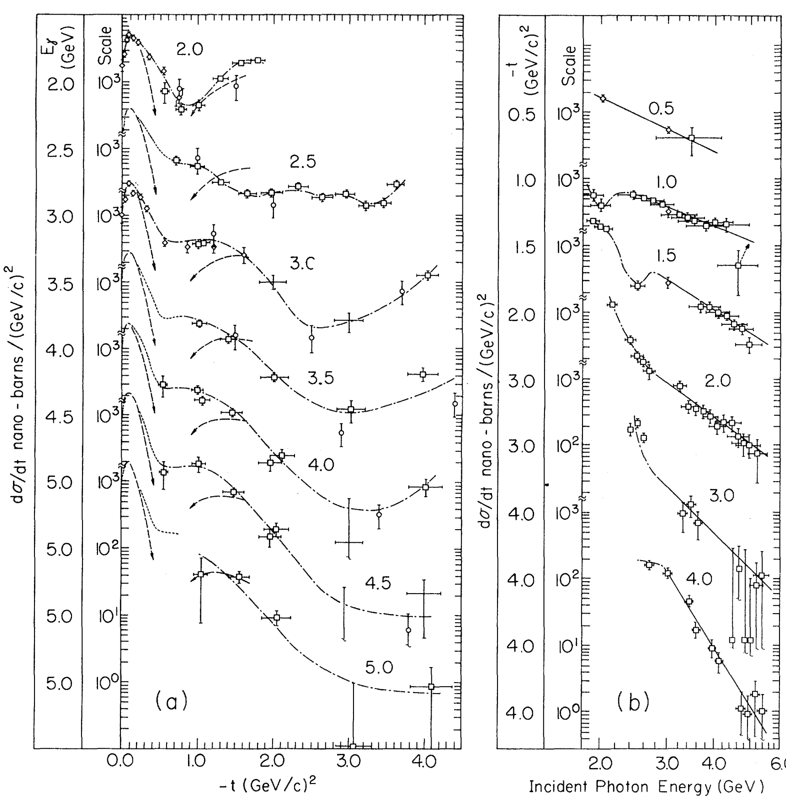

FIG. 1. (a) $d\sigma/dt$ as a function of $-t$ for several incident photon energies: squares, this experiment; circles, earlier Massachusetts Institute of Technology data (Refs. 1 and 2); diamonds, Bonn group (Ref. 4); crosses, this experiment, where the plotted data points are interpolations of data at nearby energies. The interpolation distance for these points was typically ±0.100 GeV. The curves in this figure are described in the text. (b) $d\sigma/dt$ as a function of E_γ for several values of $|t|$. The symbols used to represent different types of data points are the same as for (a). The curves through the data points are described in the text.

experiments.[6] In particular, the π^0 photoproduction cross sections in the region of baryon momentum transfers squared of 0.2 to 0.6 $(\mathrm{GeV}/c)^2$ can be expressed in the form $d\sigma/dt \propto e^{Bt}$ with $B \sim 3.0$ $(\mathrm{GeV}/c)^{-2}$. In this t range, a similar exponential behavior is observed in meson-nucleon reactions but with larger values of B and in charged meson photoproduction with $B \sim 3.0$ $(\mathrm{GeV}/c)^{-2}$. For momentum transfers larger than 0.6 $(\mathrm{GeV}/c)^2$ the $\pi^0 p$ cross sections show a break or secondary peak. As will be discussed below, this effect can be partially understood if the production amplitude is dominated by the exchange of a single Reggeized vector meson. In fact, it is most reasonable to assume that the exchanged meson is the ω.[5]

Figure 1(b) shows plots of the measured values of $d\sigma/dt$ vs incident photon energy for several values of $|t|$. For data where $E_\gamma \geq 2.8$ GeV and $|t| \geq 1.0$ $(\mathrm{GeV}/c)^2$, we have fitted the energy variation of the cross section using the Reggeized ω-exchange model.[7] These fits and the fit to the Bonn point for $|t| = 0.5$ $(\mathrm{GeV}/c)^2$ are shown as solid lines in Fig. 1(b) and the dash-dot lines are just smooth continuations of the fitted curves which are drawn to pass through the data points with $E_\gamma < 2.8$ GeV. The fits to the data with $E_\gamma \geq 2.8$ GeV determine values of $\alpha_\omega(t)$ which are shown in Fig. 2. Also plotted in this figure are the values of $\alpha_\omega(t)$ for small $|t|$ calculated from the Bonn 2.0- and 3.0-GeV data, and the ρ trajectory (dashed line) as determined by Höhler et al.[8] from an analysis of the reaction $\pi^- + p \to \pi^0 + n$. The solid line is a linear fit to the photoproduction values of $\alpha_\omega(t)$ with $|t| \leq 2.0$ $(\mathrm{GeV}/c)^2$ where the fit is constrained to pass through the ω mass at $\mathrm{Re}\,\alpha_\omega = 1$. The equation of this fit is

$$\alpha_\omega(t) = (0.47 \pm 0.03) + (0.85 \pm 0.05)t. \tag{1}$$

Without this constraint at the ω mass the best fit is

$$\alpha_\omega(t) = (0.36 \pm 0.08) + (0.71 \pm 0.11)t \tag{2}$$

which gives

$$\mathrm{Re}\,\alpha_\omega(M_\omega^2) = 0.80 \pm 0.14.$$

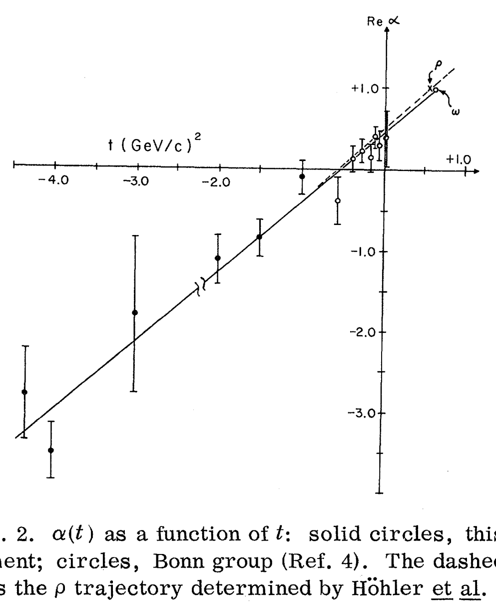

FIG. 2. $\alpha(t)$ as a function of t: solid circles, this experiment; circles, Bonn group (Ref. 4). The dashed line is the ρ trajectory determined by Höhler et al. (Ref. 8) and the solid line is Eq. (1) (see text).

Figure 2 displays three features that deserve comment. First, the values of $\alpha_\omega(t)$ are consistent, within errors, with the values of $\alpha_\rho(t)$. Second, the trajectory $\alpha_\omega(t)$ crosses zero in the region of $-t \sim 0.6$ $(\mathrm{GeV}/c)^2$. For Reggeized ω exchange the t value at which $\alpha_\omega(t)$ becomes zero corresponds to a zero in the cross section. However, the existence of a change in slope or break in the measured cross section [see Fig. 1(a)], rather than a zero, probably reflects the neglect of other contributions to the production amplitude, e.g., s-channel resonances. Third, the measured values of $\alpha_\omega(t)$ for $|t| > 2.0$ $(\mathrm{GeV}/c)^2$ are consistent with the linear extrapolation of the values at smaller $|t|$ even though the peaking at large $|t|$ apparent in the 3.0-GeV cross section is inconsistent with ω exchange being the dominant mechanism. This peaking at large $|t|$ (or small $|u|$) is characteristic of N^* exchange.[9]

The theoretical calculations of Locher and Rollnik[5] in which they assumed Reggeized ω exchange and constant residue functions are shown in Fig. 1(a) as dashed lines. These calculations agree with some of the qualitative features of the data but the main discrepancy between theory and experiment occurs at the predicted zero in the cross section. This evidence for the existence of other contributions to the production amplitude is consistent with the energy dependence of the cross sections for $E_\gamma < 2.8$ GeV, Fig. 1(b), where the cross sections also deviate from the simple Regge behavior. Also, Locher and Rollnik's theoretical calculations fail to fit the $|t|$ dependence of the cross sections for 1.5 $(\mathrm{GeV}/c)^2 \leq |t| \leq 2.5$ $(\mathrm{GeV}/c)^2$ because the assumed constant residue functions result in cross sections that do not fall off as rapidly with increasing $|t|$ as do the data.

We wish to thank Mr. P. Myers for his assistance in analyzing the data, and Dr. G. Voss and the Cambridge Electron Accelerator staff, whose excellent cooperation made this experiment possible.

*This work is supported in part through funds provided by the U. S. Atomic Energy Commission under Contract No. AT(30-1) 2098.

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[7]We have fitted the data using the single-pole functional form

$$\frac{d\sigma}{dt}=F(t)\left(\frac{E_\gamma}{M_p}\right)^{2[\alpha_\omega(t)-1]},$$

where $F(t)$ is a function of t alone, E_γ the incident photon energy, M_p the proton mass, and $\alpha_\omega(t)$ the ω Regge trajectory. When we fitted only those data points where $E_\gamma \geq 2.8$ GeV, we achieved good fits using the above functional form. The fits including data with $E_\gamma < 2.8$ GeV were poor.

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MUON-PAIR DECAY MODES OF THE VECTOR MESONS*

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(Received 10 April 1967)

We wish to present results of a further analysis of data on the production of muon pairs by a negative 12-BeV/c pion and kaon beam at the alternating-gradient synchrotron. A preliminary report of the experiment, which included a brief description of the techniques employed and of the experimental apparatus, was given previously.[1] That Letter discussed the analysis of two-prong events[2] produced in an iron-plate spark chamber and quoted results for the decay mode $\rho^0 \to \mu^+ + \mu^-$.[3] The present Letter gives four separate determinations of