[1]J. E. Mandula and R. C. Slansky, Phys. Rev. Letters 20, 1402 (1968).
[2]R. Dolen, D. Horn, and C. Schmid, Phys. Rev. 166, 1768 (1968).
[3]Christoph Schmid, Phys. Rev. Letters 20, 689 (1968).
[4]N. N. Khuri, Phys. Rev. Letters 18, 1094 (1967).
[5]H. Goldberg, Phys. Rev. Letters 19, 1391 (1967).
[6]We simply equate the "energy-averaged resonance" and Regge amplitudes, rather than equating the derivatives of their integrals (i.e., the finite-energy sum rules as done in Ref. 1.

MEASUREMENTS OF π^0 AND η^0 PHOTOPRODUCTION AT INCIDENT GAMMA-RAY ENERGIES OF 6.0-17.8 GeV*

R. Anderson, D. Gustavson, J. Johnson, and D. Ritson
Stanford Linear Accelerator Center, Stanford, California

and

W. G. Jones† and D. Kreinick
California Institute of Technology, Pasadena, California,

and

F. Murphy
University of California, Santa Barbara, California

and

R. Weinstein
Northeastern University, Boston, Massachusetts
(Received 13 June 1968)

We report on cross-sectional measurements on the photoproduction of π^0 and η^0 mesons on hydrogen for a range in t of −0.2 to −0.9 $(\text{GeV}/c)^2$ and for a range of energies 6.0-16.0 GeV. The sharp dip observed at lower energies at $t=-0.5$ for π^0 production becomes less pronounced at higher energies. This implies in the Regge framework the B^0 meson trajectory dominates at higher energies. Our one angular distribution for η^0 production at 6.0 GeV shows no dip at $t=-0.5$ as do the π^0 data.

Measurements have been made on forward π^0 photoproduction $\gamma+p\rightarrow\pi^0+p$ in the range 2-5.8 GeV.[1] The results show a pronounced dip in the cross section at a value of the square of the four-momentum transfer, $t=-0.5$ $(\text{GeV}/c)^2$. There has been considerable speculation on the energy dependence of this process at higher energies.[2] We have recently completed measurements at incident photon energies up to 17.8 GeV.

A collimated beam of bremsstrahlung photons from the Stanford Linear Accelerator Center linear accelerator irradiated the liquid-hydrogen target, a 12-in. long by 2-in. diam thin Mylar cylinder. The yield of protons recoiling from the target was measured as a function of angle for a variety of proton momenta and primary energies.

The measurements were made with a 100-in. radius, 90°-bend, second-order–corrected spectrometer[3] which focused momenta and production angles in a single focal plane normal to the impinging particles. The dispersion of this spectrometer was 1.66 in. per percent in momentum, and 0.32 in. per mrad in production angle. Protons were identified and separated from pions on the basis of ionization loss in three trigger counters and by vetoing pions with a Lucite Cherenkov counter. At all momenta, pion contamination was less than a few percent of the proton signal. The trigger counters were put in coincidence with eight hodoscope counters 10 in. by $\frac{3}{4}$ in. by $\frac{1}{4}$ in. thick located at the focal plane. The whole counter assembly was rotatable so that the axes of the hodoscope counters could be aligned with kinematic "missing-mass lines" in the focal plane. The resolution of the apparatus was limited by the multiple Coulomb scattering of particles in the liquid-hydrogen target.

The beam intensity was continuously monitored with both a Cherenkov monitor and secondary-emission quantameter. The secondary-emission

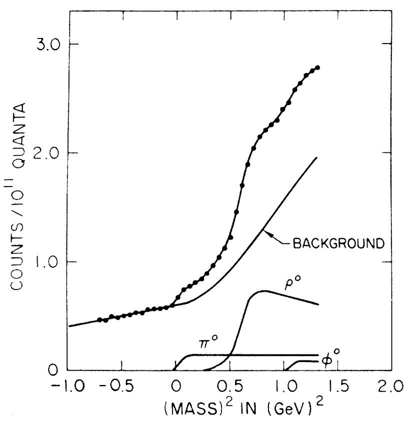

FIG. 1. A typical yield curve taken at a peak bremsstrahlung energy of 11.5 GeV and $t = -0.7$ $(\mathrm{GeV}/c)^2$. Yield in counts per hodoscope counter per 10^{11} equivalent quanta is plotted as a function of "missing-mass squared." The fitted contributions of the background and the π^0, ρ^0, and φ^0 yields are shown.

quantameter was periodically calibrated against a silver calorimeter to obtain an absolute calibration. Typical beam intensities were of the order of 10^{11} equivalent quanta per second, and counting ranged from 5×10^2 to 50 counts per second.

π^0 and η^0 cross sections were determined by measuring the proton yield as a function of angle above and below their kinematic thresholds. Figure 1 shows a typical yield curve obtained with a peak bremsstrahlung energy of 11.5 GeV, and a recoiling proton momentum corresponding to $t = -0.7$ $(\mathrm{GeV}/c)^2$. The protons in the negative missing-mass-squared region are kinematically forbidden for single processes and are attributable to double processes within the target (these "ghost protons" are frequently observed in π^0 photoproduction experiments). The background was phenomenologically fitted with a polynomial (Fig. 1 shows this fit). Under the conditions of our experiment Compton scattered protons were not resolved from those associated with π^0 production. η^0 production was not well resolved from ρ^0 production at higher energies and results are given only for 6-GeV incident protons.

Yields were translated into cross sections taking into account the spectrometer acceptance, the trigger-counter efficiencies, and the bremsstrahlung-beam calibration. Conservative errors on the yields and cross sections were applied to allow for uncertainties in the background subtractions. Figure 2 shows the cross sections $d\sigma/dt$ obtained for π^0 production at photon energies of 6, 11 and 16 GeV. These cross sections

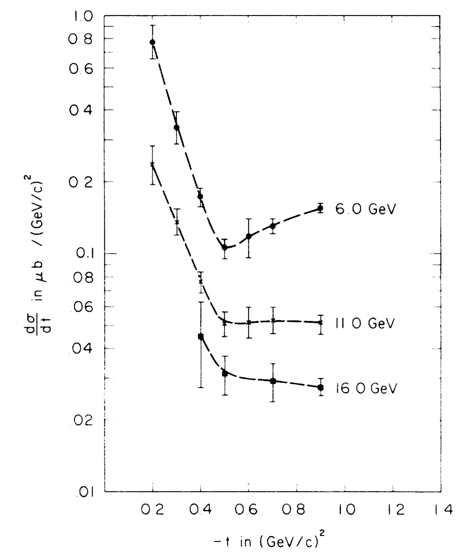

FIG. 2. $d\sigma/dt$ for π^0 photoproduction in $\mu\mathrm{b}/(\mathrm{GeV}/c)^2$ vs $-t$ in $(\mathrm{GeV}/c)^2$ for 6-, 11-, and 16-GeV primary photon energies. Dashed lines have been drawn through the points to guide the eye.

have been corrected for Compton scattering using the vector-dominance model to estimate the Compton cross section: $d\sigma/dt\,(\mathrm{Compton}) \approx 0.3 \times e^{-8|t|}$ $\mu\mathrm{b}/(\mathrm{GeV}/c)^2$.[4] (This correction varies from ~1 to ~15% in the worst case.) Agreement of our 6-GeV photoproduction results with the Deutsches Elekronen-Synchrotron photoproduction results at 5.8 GeV is excellent.

Photoproduction of π^0 mesons at forward angles can proceed via the exchange of ω^0 or B^0 mesons in the t channel. In the framework of the Regge theory it had previously been hypothesized that B^0 meson exchange would become less important at high energies and that the process would be dominated by ω^0 exchange (the one-ω-exchange model). It was therefore predicted[2] that the π^0 photoproduction cross section would behave like the $\pi^- + p \to \pi^0 + n$ charge-exchange cross section, where only ρ exchange is permitted, i.e., that $d\sigma/dt$ would show both a shrinking of the forward peak with increasing energy and a sharp dip at $t \approx -0.5$ $(\mathrm{GeV}/c)^2$. In fact, our results show that the dip at $t = -0.5$ $(\mathrm{GeV}/c)^2$ becomes less deep at high energies and that the shrinkage is less strong than would be predicted from Reggeized ω^0 exchange. For instance at $t = -0.9$ $(\mathrm{GeV}/c)^2$ the effective α in $d\sigma/dt \sim s^{2\alpha-2}$ is 0.05 ± 0.06, whereas one would expect from the ω^0 trajectory a value of α equal to -0.4.

If we interpret our results in the conventional Regge framework with only poles, we would infer

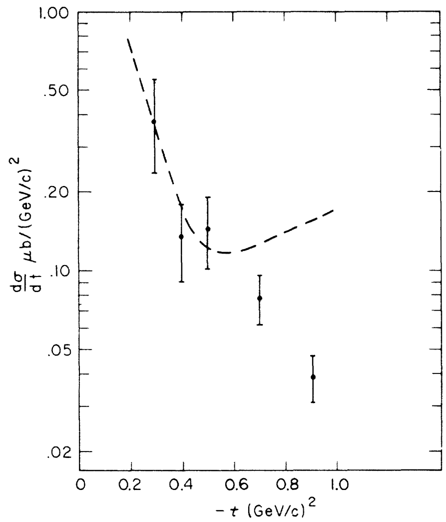

FIG. 3. $d\sigma/dt$ for η^0 photoproduction in μb/(GeV/c)^2 vs $-t$ in (GeV/c)^2 at a primary energy of 6 GeV. The dashed line, taken from Fig. 2, shows π^0 production for comparison.

that the B^0 meson Regge trajectory is rather flat and dominates the behavior at moderate t values and high energies.

Figure 3 shows the η^0 cross section $d\sigma/dt$ as a function of t at 6-GeV primary photon energy. For comparison the dashed line shows the π^0 cross section. The η^0 cross section falls monotonically as a function of t and shows no dip at $t \approx -0.5$ (GeV/c)^2. We therefore would conclude that photoproduction of η^0 mesons at moderate t values does not proceed predominately via Reggeized ρ^0 meson exchange.[5] In summary, while other explanations are not ruled out, we would conclude in the framework of conventional Regge theory that both ω^0 and B^0 Regge exchange are important for π^0 photoproduction and that, contrary to expectation, the B^0 trajectory dominates at moderate t values and high energies. For η^0 photoproduction we would conclude that the Reggeized ρ^0 exchange does not play a dominant role.

We are indebted to F. Gilman for helpful discussions, and to the operations and support crews at the Stanford Linear Accelerator Center for their efficient cooperation.

---

*Work supported by the U. S. Atomic Energy Commission.

†On leave of absence from Imperial College, London, England.

[1]M. Braunschweig, D. Husman, K. Lübelsmeyer, and D. Schmitz, Phys. Letters 22, 705 (1966); G. C. Bolon, D. Garelick, S. Homma, R. Lewis, W. Lobar, D. Luckey, L. S. Osborne, R. Schwitters, and J. Uglum, Phys. Rev. Letters 18, 926 (1967). A summary is provided by B. Richter, in the International Symposium on Electron and Photon Interactions at High Energies, Stanford Linear Accelerator Proceedings (Clearing House of Federal Scientific and Technical Information, Washington, D. C., 1968), p. 309.

[2]A summary of theoretical work is given by H. Harari, in the International Symposium on Electron and Photon Interactions at High Energies, Stanford Linear Accelerator Proceedings (Clearing House of Federal Scientific and Technical Information, Washington, D. C. 1968), p. 337. See also A. Dar and V. Weisskopf, to be published.

[3]The Stanford Linear Accelerator Center 1.6-GeV/c spectrometer is described in the Stanford Linear Accelerator Center Users Handbook, 1966 (unpublished), Sec. E.

[4]We assumed from the vector-dominance model that $d\sigma(\gamma+p\rightarrow\gamma+p)/dt=\kappa d\sigma(\gamma+p\rightarrow\rho+p)/dt$ and chose $\kappa\approx 3.6\times10^{-3}$. The cross section $d\sigma(\gamma+p\rightarrow\rho+p)/dt$ was approximated from our own experimental data (to be published).

[5]A. Dar and V. Weisskopf, Phys. Rev. Letters 20, 726 (1968), calculated η^0 photoproduction from a comparison with $\pi^-+p\rightarrow\omega^0+n$. Our results do indeed follow their predictions but are ~1.5 higher. However, their calculations are based on the implicit assumption that η^0 photoproduction and $\pi^-+p\rightarrow\omega^0+n$ are both dominated by ρ exchange.