clude more partial waves would be premature.

In the case of πN scattering, the maximum of the secondary peak is slightly shifted and is located at about $\cos\theta = 0.2$. This indicates that more than a single partial wave in the spin-flip amplitude would be necessary for a good fit.

A test for the presence of the spin-flip amplitude would be provided by the polarization experiments in the energy range of these experiments. In the case of KN scattering, the polarization is expected to show a sharp maximum as a function of the scattering angle at about $\cos\theta = 0.4$-0.6 and to fall off rapidly when $\cos\theta$ is not in this range. Thus, it would be extremely valuable to have polarization measurements in these experiments.

We should like to thank Leona Marshall for stimulating discussions.

*Work supported in part by the U. S. Air Force Office of Scientific Research and the National Science Foundation.

[1]D. E. Damouth, I. W. Jones, and M. I. Perl, Phys. Rev. Letters 11, 287 (1963).

[2]R. Crittendon, H. J. Martin, W. Kernan, L. Leipuner, A. C. Li, F. Ayer, L. Marshall, and M. L. Stevenson, Phys. Rev. Letters 12, 424 (1964).

[3]L. M. Simmons, Phys. Rev. Letters 12, 229 (1964).

[4]J. S. Blair, Phys. Rev. 108, 827 (1957).

[5]Reference 3, and A. Dar, M. Kugler, Y. Dothan, and S. Nussinov, Phys. Letters 11, 265 (1964).

[6]V. P. Kanavetz, I. I. Levinton, B. V. Morozov, and M. D. Shafranov, Phys. Letters 7, 165 (1963).

[7]R. Serber, Phys. Rev. Letters 10, 357 (1963); A. D. Krisch, Phys. Rev. Letters 11, 217 (1963); J. Orear, Phys. Rev. Letters 12, 112 (1964); A. Dar, M. Kugler, Y. Dothan, and S. Nussinov, Phys. Rev. Letters 12, 82 (1964).

PHOTOPRODUCTION OF THE ρ^0 MESON*

A. D. Franklin, D. R. Rust, A. Silverman, C. K. Sinclair, and R. M. Talman
Cornell University, Ithaca, New York
(Received 6 August 1964; revised manuscript received 14 September 1964)

We report here the results of an investigation of the reaction

$$\gamma + p \to \pi^+ + \pi^- + p, \tag{1}$$

whose primary purpose was to investigate ρ^0-meson photoproduction. The mass distribution of the (π,π) system over a range of masses substantially larger than the ρ^0 width was measured and evidence on the angular distribution of ρ^0-meson photoproduction was obtained.

We counted two of the final-state particles and measured their angles and momenta. This information provided just enough information to determine the kinematics, assuming no other particles produced. For (π,π) masses $\gtrsim 700$ MeV, the production of three or more pions was energetically forbidden. Generally, the particles observed were the proton and one of the pions. Measurements were made detecting both combinations $(p,\pi^+$ and $p,\pi^-)$. In one case, in order to detect the ρ^0 near zero degrees, the arrangement was altered to detect the two pions.

The experimental arrangement is shown in Fig. 1. The γ-ray beam from the Cornell synchrotron, after collimation, passed through a hydrogen target and into a Quantameter which measured its total energy. Pions produced in the target passed through the uniform field magnet M1 and were detected in the scintillation counters S_1, S_2, S_3, and S_6. Protons produced in the target passed through the rectangular quadrupole magnet M2 and were detected in scintillation counters S_4, S_5, and S_7. S_4, S_5, and S_7 were required to have pulse heights at least 1.5 times minimum. A coincidence between S_1, S_2, S_3, S_4, S_5, S_6, and S_7 triggered three spark chambers in M1 and two behind M2, from which the pion and proton trajectories, and hence angles and momenta, were determined. To reduce multiple scattering, the spark-chamber plates in M1 were made of 0.001-in. aluminum. The pion's angle and momentum were determined from the track positions in the three chambers and its trajectory was projected back to its intersection with the target. The target position and the tracks in the two spark chambers behind M2 were used to determine the angle and momentum of the proton. Pions with momentum p_π between 440 MeV/c and 710 MeV/c and protons with momentum p_p between 400 MeV/c and 900 MeV/c were detected. The square of the invariant mass of the (π,π)

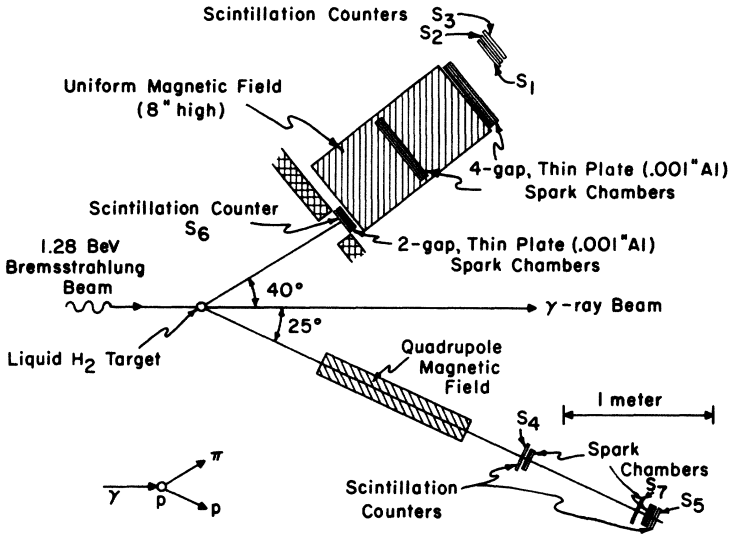

FIG. 1. Experimental layout.

system, $M_{\pi\pi}{}^2$, was determined to an accuracy of about 3%.

Data were taken under the following conditions:

$$\theta_\pi = 40°, \quad \theta_p = 15°, 20°, 25°, 35°;$$

$$\theta_\pi = 47°, \quad \theta_p = 30°, 35°, 40°;$$

$$\theta_{\pi 1} = 47°, \; \theta_{\pi 2} = 47° \; (\rho^0 \text{ produced near } 0°);$$

where θ_π is the lab angle of the detected pion, and θ_p is the lab angle of the proton.

33 000 pictures were taken (approximately equal numbers in each configuration), of which somewhat more than half yielded analyzed events. The peak γ-ray energy was 1275 MeV for all runs except the last listed, where it was 1225 MeV. The empty-target rate was generally about 5%. The accidental rate was about 2% when the π^- was detected and about 10% when the π^+ was detected.

Since we did not have a 4π detector and in fact measured process (1) over only a very small fraction of the allowed phase space, we are unable to present our data in the form of Dalitz dot plots. Instead we calculate the invariant matrix element M (essentially the density of points in a Dalitz plot). Another complication is that our incident photon beam was not monoenergetic and our equipment was sensitive to incident laboratory γ-ray energies, K_L, between 900 MeV and 1275 MeV. For a fixed K_L, M would be constant if Reaction (1) were completely isotropic, and in that case the distribution of all relevant quantities would be predicted by invariant phase space. If, in addition, M were independent of K_L, the total cross section σ_T would increase with energy. This hypothesis is inconsistent with the results of Chasan et al.[1] that σ_T is fairly constant (about 60 μb) for 600 MeV $< K_L <$ 1000 MeV. We therefore compare our date not with the prediction of constant M (invariant phase space) but with this prediction modified by a factor, depending only on K_L, which keeps σ_T constant. In other words, we compare our data to a "phase space" model in which there is constant total cross section and complete isotropy. This comparison is conveniently performed by quoting for each of our measured points that $\sigma_T(K_L)$ which, with complete isotropy, would yield our observed counting rates. The relation between $\sigma_T(K_L)$ and M is

$$\sigma_T(K_L) = \frac{1}{64\pi^5}\frac{|M|^2}{M_p K_L} R_3(K_L),$$

where M_p = mass of the proton and $R_3(K_L)$ is the total phase space as defined by Hagedorn.[2] The factor relating σ_T and $|M|^2$ is constant to within a factor of about 1.5 over our data. $|M|^2$ is calculated from the directly measured quantity $d^3\sigma/dP_p d\Omega_p d\Omega_\pi$ by the formula given in McLeod, Richert, and Silverman.[3]

The measurements of McLeod, Richert, and Silverman have shown that for $K \simeq 1100$ MeV the process

$$\gamma + p \to p + \rho^0, \quad \rho^0 \to \pi^+ + \pi^- \tag{2}$$

contributes importantly to Reaction (1). In this experiment we try to isolate this two-body reaction and measure its angular dependence. Even if the ρ^0 meson shows up clearly it is difficult to extract the cross section for (2) because of interference with other channels in (1). In particular, the process

$$\gamma + p \to N^{*++}(\tfrac{3}{2},\tfrac{3}{2}) + \pi^- \\ \quad\quad \hookrightarrow p + \pi^+ \tag{3}$$

might cause trouble. The process like (3) but with the neutral isobar (p,π^-) is less likely to be important.[4] Our experimental configuration was such that when we detected the π^-, the (p,π^+) system was below but near the 3, 3 resonance, while the (p,π^-) system was well above. (The invariant mass $M_{p\pi^+}$ was between 1.10 and 1.25 BeV while $M_{p\pi^-}$ was between 1.35 and 1.55 BeV.) When we detected the p and the π^+ the reverse was true. As a result we expect the 3, 3 isobar to influence the p and π^+ data less than the p and π^-. This in fact turns out to be true since the ρ^0 stands out clearly in the latter case but not in the former. Hence, we present here only the data taken detecting the p and π^+. This argument plus the fact that we intentionally kept $M_{p\pi^+}$ and $M_{p\pi^-}$ more or less constant leads us to believe that the 3, 3 isobar is of little importance in the data presented (except possibly in the upper left-hand graph of Fig. 3).

The raw data of the experiment consist of the numbers of counts in particular intervals of the laboratory variables p_p, p_π, θ_p, and θ_π. A sample of the data in that form is shown in Fig. 2. The smooth curves show the result expected from isotropic production with a constant total cross section of 100 μb. Also shown is a scale of $M_{\pi\pi}$ [the invariant mass of the (π,π) system]. Unfortunately, the phase space is not much wider than the ρ region. This is not too serious for $M_{\pi\pi}$ below the ρ mass since other data (see Fig. 3) extend the phase space in that direction. But we are excluded from the high $M_{\pi\pi}$ region by limitations in our beam energy. Hence, it must be conceded that our data showing the falloff above the ρ are weak. With this reservation, it seems clear that the ρ is making a significant contribution to the data of Fig. 2.

We plot in Fig. 3 our measured value of σ_T, defined above, which also is 100 μb times the ratio of histogram to phase space in plots such as those of Fig. 2. For investigating the effect of the ρ we plot σ_T as a function of $M_{\pi\pi}$ for fixed range of $\theta_{\pi\pi}$ [the production angle of the (π,π)

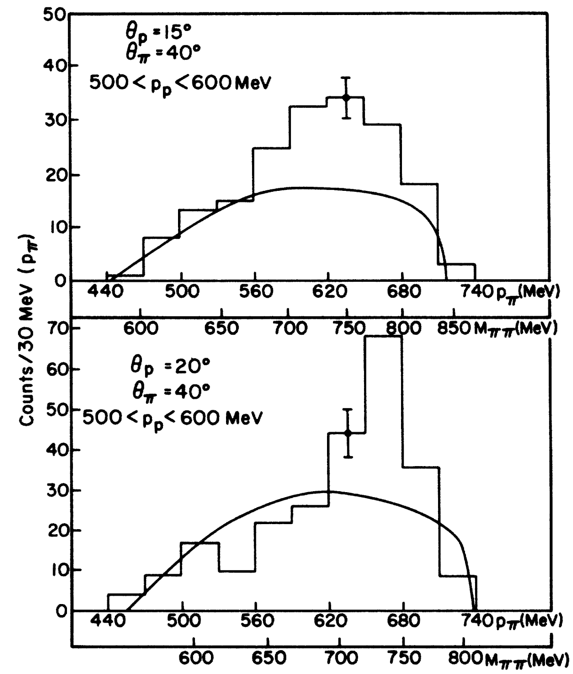

FIG. 2. Sample histograms showing the raw data at the particular configurations indicated. The smooth curves show the result expected from isotropic production with a constant total cross section of 100 μb.

system in the overall c.m.]. Unfortunately various other dependences (particularly on K_L) are thus suppressed. To the extent that the data fall on smooth curves the suppressed variables are unimportant. In particular, the data have the same character independent of K_L.

The features of the data we wish to point out are these: (1) ρ^0 production is a significant contribution to π-pair photoproduction; and (2) the ρ^0 photoproduction cross section seems to be largest near a c.m. ρ^0 angle of 60° and to fall off both backward and forward of this.

We would like to regard the data of Fig. 3 as a measurement of a "foreground" of ρ production plus a "background" of other things. In that light there is little background in the range $45° < \theta_{\pi\pi} < 81°$, and what there is one could perhaps subtract.

On the other hand, in the rest of our data the contribution of the ρ is not obvious and indeed that is the evidence for feature (2). As is conventional in that case, we could perhaps quote an upper limit to the foreground. Unfortunately the situation is more complicated than foreground plus background since there is the possibility of destructive interference. Nevertheless, we feel that feature (2) can usefully be made more quan-

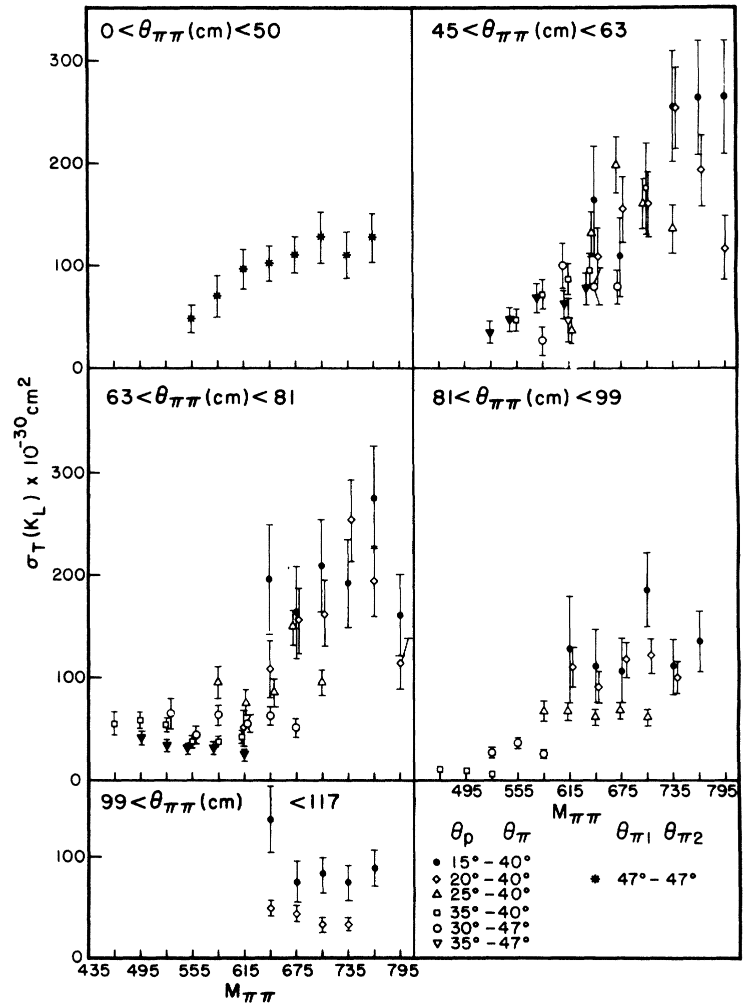

FIG. 3. Each point plotted represents the density of events at a particular point in phase space, specified by $\theta_{\pi\pi}$, $M_{\pi\pi}$, θ_p, and θ_π. The density is represented by that artificial total cross section $\sigma_T(K_L)$ which would result if the density of events throughout phase space were constant and given by the measured value.

titative. To do that we assume that all events near $M_{\pi\pi} = 750$ MeV come from ρ's and that the shape as a function of $M_{\pi\pi}$ is independent of $\theta_{\pi\pi}$ and is given by a Breit-Wigner form with $\Gamma = 100$ MeV. Under these assumptions we calculate $d\sigma/d\Omega$, the c.m. differential cross section for ρ production from our measured value of the differential cross section for producing π-π systems per unit interval of $M_{\pi\pi}$ at $M_{\pi\pi} = 750$ MeV. These values are shown in Table I.

We emphasize that this differential cross section includes some background and also that any effects of ρ polarization have been neglected in its derivation.

Berman and Drell[5] have suggested that ρ^0 production be dominated by one-pion exchange with one consequence being that the differential cross section be maximum at 0°. On the other hand, Bronzan and Low[6] suggest that the ρ, π, γ vertex is suppressed and also, therefore, the one-pion exchange. Our data, while in no way decisive, seem to favor the second hypothesis.

We would like to thank Professor S. Richert

Table I. C.m. differential cross section for ρ^0 photoproduction (see text for assumptions).

$\theta_{\pi\pi}$	$d\sigma/d\Omega$ (μb/sr)
0-50	2.0 ±1.0
45-63	4.4 ±1.3
63-81	3.6 ±2.1
81-99	2.1 ±0.8
99-117	1.3 ±0.6

for his participation and valuable contribution to the early stages of this experiment.

---

*Research supported in part by the U. S. Office of Naval Research.

[1]B. M. Chasan, G. Cocconi, V. T. Cocconi, R. M. Schectman, and D. H. White, Phys. Rev. 119, 811 (1960).

[2]R. Hagedorn, Relativistic Kinematics (W. A. Benjamin, Inc., New York, 1963), p. 114, Eqs. 7-58.

[3]D. McLeod, S. Richert, and A. Silverman, Phys. Rev. Letters 7, 383 (1961). The present data are in substantial agreement with the data of this reference.

[4]R. E. Cutkosky and F. Zachariasen, Phys. Rev. 103, 1108 (1956).

[5]Under the assumption that the one-pion exchange dominates process (2), S. M. Berman and S. D. Drell [Phys. Rev. 133, B791 (1964)] inferred a decay width $\Gamma(\rho^0 \to \pi^0 + \gamma) \approx 0.5$ MeV using the data of reference 3. The present data suggest a much smaller value although the decrease we observe in the forward direction could be the result of interference with the 3, 3 isobar since for those data $M_{p\pi^+}$ was near the resonance energy.

[6]J. B. Bronzan and F. E. Low, Phys. Rev. Letters 12, 522 (1964).

DO HYPERPHOTONS EXIST?*

Steven Weinberg†
Department of Physics and Lawrence Radiation Laboratory, University of California, Berkeley, California
(Received 4 September 1964)

The existence of the photon naturally suggests that there may also exist other "gauge" particles, coupled to other conserved currents.[1,2] This remained purely a speculation, until the recent appearance of experimental results[3] which seem to indicate a CP-violating $K_2^0 \to 2\pi$ decay. Independent Letters by Bell and Perring[4] and by Bernstein, Cabibbo, and Lee[5] have pointed out that the effect observed can also be interpreted as the regeneration of K_1^0 by a new long-range interaction between the K meson and our galaxy, which would have to act with opposite sign on the K^0 and $\bar{K}^0$ components. Both Letters therefore suggest the existence of spin-one "hyperphotons" coupled to hypercharge (Y), or to Y plus some linear combination of Q and N. The purpose of this note is to argue on empirical grounds against the existence of such hyperphotons, and to indicate where to find them if they do exist.

The hypercharge current is not precisely conserved, so the hyperphoton must[6] have a small but finite mass m. But in all other respects it may be presumed to behave qualitatively like an ordinary photon. We can therefore calculate the matrix element for K^0 decay into two pions and a soft hyperphoton, of momentum q^μ [with $q^0 = \omega \equiv (|\vec{q}|^2 + m^2)^{1/2}$] and polarization ϵ^μ, as[7]

$$M(q,\epsilon) = \frac{fM}{(2\pi)^{3/2}(2\omega)^{1/2}} \frac{2P_K \cdot \epsilon}{(P_K - q)^2 + m_K^2}, \qquad (1)$$

where f is the coupling constant of K^0 to the soft hyperphoton, and M is the matrix element for $K^0 \to 2\pi$. The branching ratio for emission of hyperphotons of energy $\leq E$ in K^0 decay at rest is then

$$\frac{K^0 \to 2\pi + \text{“}\gamma\text{”}}{K^0 \to 2\pi} = \frac{f^2}{4\pi^2 m^2} \int_m^E \frac{(\omega^2 - m^2)^{3/2}}{(\omega - m^2/2m_K)^2} d\omega. \qquad (2)$$

This formula is exact for sufficiently small E and m (say, $\ll 100$ MeV) because then the matrix element is completely dominated by the pole term (1).[7] If we take E of order 100 MeV, and assume (quite safely) that $m \ll E$, then (2) becomes simply

$$\frac{K^0 \to 2\pi + \text{“}\gamma\text{”}}{K^0 \to 2\pi} \cong \frac{f^2 E^2}{8\pi^2 m^2}. \qquad (3)$$

The important point is that (3) depends only upon the ratio f^2/m^2, so a very weak coupling can still give a large branching ratio if m is sufficiently small. This circumstance can be traced back to the longitudinal term $q_\mu q_\nu/m^2$ in the polarization sum, which contributes here because K decay violates hypercharge conservation. Similar conclusions would hold for any $\Delta S \neq 0$ decay process.

How large is f^2/m^2? The apparent $K_2^0 \to 2\pi$ decay rate can be explained by regeneration of K_1^0 if the K^0 and $\bar{K}^0$ are split by the hyperphoton field by an amount $V \cong 10^{-8}$ eV. If hyperphotons interact purely with hypercharge, then

$$V = f^2 \int d^3r\, n(\vec{r}) e^{-mr}/4\pi r, \qquad (4)$$

where $n(\vec{r})$ is the nucleon number density at position $\vec{r}$ (with K meson at $\vec{r} = 0$). Hence f^2/m^2 must take the value

$$f^2/m^2 = V/\langle n \rangle, \qquad (5)$$