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Determination of the Real Part of the ρ-Nucleon Forward Scattering Amplitude and the Relative ρ-ω Production Phase

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The real part of the ρ-nucleon forward scattering amplitude has been obtained by a measurement of the photoproduction of asymmetric electron-positron pairs from a carbon target. A determination of the relative ρ-ω production phase is also made. At a mean incident photon energy of 4 GeV the ratio of the real to the imaginary part of the ρ-nucleon amplitude is found to be -0.28 ± 0.12.

The idea that ρ-nucleon (ρN) forward scattering does not proceed by a purely absorbtive mechanism was suggested[1] as a possible explanation for the difference between the values of the ρ-photon coupling constant obtained from ρ-photon production data[2] and colliding beam experiments.[3] In order to bring the photoproduction value into reasonable agreement with colliding beam results, it was necessary to use a value of $\alpha_{\rho N}$, the ratio of the real to the imaginary part of the ρN forward scattering amplitude, as large as -0.45 at an incident energy of 5–6 GeV.

The present experiment was carried out primarily to measure the phase of the coherent ρN forward scattering amplitude by a direct method if vector dominance is assumed, using the process

$$\gamma + A \to A + \rho, \quad \rho \to e^+e^-,$$

where the resultant electron pairs are detected asymmetrically. In addition, the experiment will give an independent determination of the ρ-ω production phase previously measured with our symmetric configuration.[4]

In the invariant-mass region of the ρ meson, the amplitude for the photoproduction of electron pairs consists of contributions from the Bethe-Heitler (BH) process, the Compton process including ρ and ω mesons,[4,5] and possible incoherent processes. As a consequence of charge-conjugation invariance, the cross section arising from the interference between the BH and Compton amplitudes involves only electron pairs in which the electrons have unequal four-momenta. A measurement of asymmetric electron pairs, therefore, provides a means of obtaining the relative phase of these amplitudes, and hence, since the BH amplitude is real, the phases of the ρ-nucleus and ω-nucleus forward scattering amplitudes.

The differential BH-Compton interference cross section is written

$$\frac{d\sigma_I}{dp^+dp^-d\Omega^+d\Omega^-} = \frac{Z\alpha^{5/2}}{\pi^2}\frac{\epsilon^+\epsilon^-}{M}\frac{G_E(t)e^{-bt/2}}{t}\frac{1}{\gamma_\rho}\left(\frac{m_\rho}{m}\right)^2\left(\left.\frac{d\sigma_{\gamma A}}{dt}\right|_{t=0}\right)^{1/2}K_I(p^+,p^-,\epsilon^+,\epsilon^-)$$

$$\times \mathrm{Re}\left\{i\exp(i\varphi_{\rho A})\left[\frac{1}{m^2-m_\rho^2+im_\rho\Gamma_\rho(m^2)}+\left(\frac{\gamma_\rho}{\gamma_\omega}\right)^2\left(\frac{m_\omega}{m_\rho}\right)^2\frac{\exp(i\varphi_{\rho\omega})}{m^2-m_\omega^2+im_\omega\Gamma_\omega}\right]\right\},$$

where $\Gamma_\rho(m)$ has the usual Jackson[6] form and $K_I(p^+,p^-,\epsilon^+,\epsilon^-)$ is a kinematic factor. Also Z, M, and $G_E(t)$ are the respective nuclear charge, nuclear mass, and the electric form factor of the target; $\epsilon^\pm$ and $p^\pm$ are the energies and four-momenta of the pair electrons, respectively; t is the square of the four-momentum transfer to the nucleus; m_V and Γ_V are the mass and width of vector meson V; $em_V^2/2\gamma_V$ is the photon–vector-meson coupling constant; m_π is the pion mass and m is the invariant pair mass. The relationship between the phase angles $\varphi_{\rho A}$ and $\varphi_{\omega A}$ of the coherent ρ- and ω-nucleus amplitudes is $\varphi_{\omega A} = \varphi_{\rho A} + \varphi_{\rho\omega}$, where $\varphi_{\rho\omega}$ is the phase angle between the ρ and ω photoproduction amplitudes.

For a complex target nucleus it has been shown[7] that in addition to the ρ-nucleon phase angle $\varphi_{\rho N}$, the measured total scattering phase angle $\varphi_{\rho A}$ contains a contribution due to refraction and absorption of the vector meson within the nucleus. This latter quantity is given by the relationship $\varphi_{\rho A} = \varphi_{\rho N} + \theta(\varphi_{\rho N}, R)$, where θ is the additional phase change due to a nucleus of radius R. Carbon, with a very small value of $\theta(\varphi_{\rho N}, R)$, was found to be a suitable target material.

The experiment was carried out using a magnetic pair spectrometer. Its properties are described elsewhere.[4,5] A total mass range of 590–830 MeV/c^2 and transverse momentum range of 0–150 MeV/c were covered. Only asymmetric pairs were detected.

Let $N^{\pm}$ denote the pair yield when leptons ($e^{\pm}$) are detected at the smaller spectrometer-arm angle, the momenta in the arms being equal. At each configuration of the apparatus, half of the data, N^+, were obtained with one set of magnet polarities, and the other half, N^-, with the polarities reversed. The number of events in each mass bin, $N^{\pm}(m^2)$, arises from several contributions to the cross section:

$$N^{\pm}(m^2) = N_{\mathrm{BH}}(m^2) + N_V(m^2) \pm [N_{\mathrm{BH},V}(m^2) + N_{2\mathrm{B}}(m^2)],$$

where $N_{\mathrm{BH},V}$ is the BH-Compton interference yield, and $V = \rho$, ω, $\rho\omega$ interference. The yield $N_{2\mathrm{B}}$ arises from the interference of the first and second Born amplitudes in wide angle pair production.[8] The data $d\sigma_{N^{\pm}}(m^2)$ are presented in Fig. 1. For each mass bin, the combination $(N^+ - N^-)/2$ corresponds to the BH-Compton interference yield, whereas the combination $(N^+ + N^-)/2$ corresponds to the sum of the BH and Compton yields, including ρ-ω interference.

If the interference cross section $d\sigma_I$ is fitted directly to the experimental data, the resultant values of the phases $\varphi_{\rho A}$ and $\varphi_{\omega A}$ are not well determined because of the uncertainties in the values of the parameters m_ρ, Γ_ρ^0, γ_ρ, $[d\sigma/dt]_{t=0}$, and the slope b of the t dependence, and any error in the experimental normalization. However, by using a particular combination of yields,

$$\epsilon(m^2) = \frac{(N^+ - N^-)/2}{\{[(N^+ + N^-)/2 - N_{\mathrm{BH}}]N_{\mathrm{BH}}\}^{1/2}} = \frac{d\sigma_1 + d\sigma_{2\mathrm{B}}}{(d\sigma_{\mathrm{C}}\, d\sigma_{\mathrm{BH}})^{1/2}},$$

the parameters $[d\sigma_{VA}/dt]_{t=0}$ and b are removed from the analysis and the dependence upon m_ρ, γ_ρ, and the normalization is greatly reduced. The yield N_{BH} was calculated from the theoretical cross section.

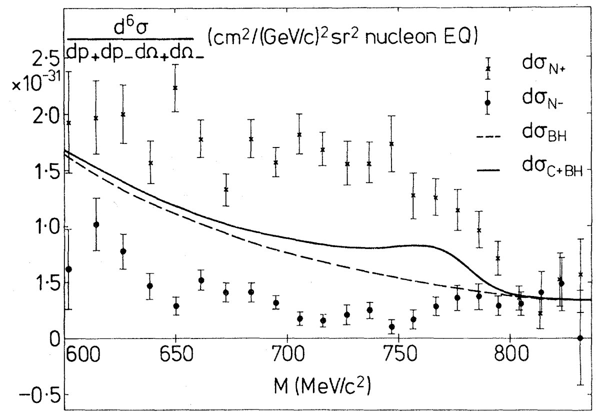

FIG. 1. The differential cross section for the $N^{\pm}$ yields as a function of invariant pair mass. The dashed line is the theoretical BH cross section, and the continuous line is the sum of the BH and fitted Compton cross sections.

The data $\epsilon(m^2)$ were fitted allowing the parameters $\varphi_{\rho A}$ and $\varphi_{\rho\omega}$ to be variable, and fixing the parameters m_ρ, Γ_ρ^0, m_ω, Γ_ω, and $\gamma_\omega^2/\gamma_\rho^2$ at the values 768 MeV/c^2, 146 MeV/c^2, 783.4 MeV/c^2, 12.6 MeV/c^2, and 7.0, respectively.[9,10] The best fit to the data [Fig. 2(a)] gives $\varphi_{\rho A} = 16.5° \pm 6.2°$ and $\varphi_{\rho\omega} = 118°{}^{+13°}_{-22°}$.

The sensitivity of the best fit to variations of the above fixed parameters was investigated. By far the largest contribution to the error in $\varphi_{\rho A}$, amounting to $\pm 2.1°$, results from an uncertainty of ± 5 MeV/c^2 in m_ρ. However, this contribution does not significantly modify the best-fit errors.

The value of $\alpha_{\rho N}$ was calculated from the measured phase angle $\varphi_{\rho A}$. For $\varphi_{\rho A}$ in the region 15–20°, $\theta(\varphi_{\rho N}, R) \sim 1°$, giving the result $\alpha_{\rho N} = -\tan\varphi_{\rho N} = -0.28 \pm 0.12$ at a mean photon energy of 4 GeV. A recent determination of $\alpha_{\rho N}$ at a mean photon energy of 5 GeV, in a similar experiment,[11] found $\alpha_{\rho N} = -0.2 \pm 0.1$. Another experiment measuring the electroproduction of muon pairs from carbon[12] obtained $\varphi_{\rho A} = 16° \pm 22°$.

In order to look for variation of $\varphi_{\rho A}$ with invariant pair mass, the data $\epsilon(m^2)$ were fitted at each mass setting. It was found, however, that fitting by a function of the real part of the total Breit-Wigner plus ρ-nucleon phase could not produce unique values of $\varphi_{\rho A}$ in the region of the ρ mass [Fig. 2(b)]. The constraint that $\varphi_{\rho A}$ is mass independent provides a unique solution when the total mass spectrum is fitted, corresponding to the lower values of $\varphi_{\rho A}$.

The internal consistency of the data was checked by fitting the cross-section combinations $(d\sigma_{N^+} + d\sigma_{N^-})/2$ and $(d\sigma_{N^+} - d\sigma_{N^-})/2$ separately. The

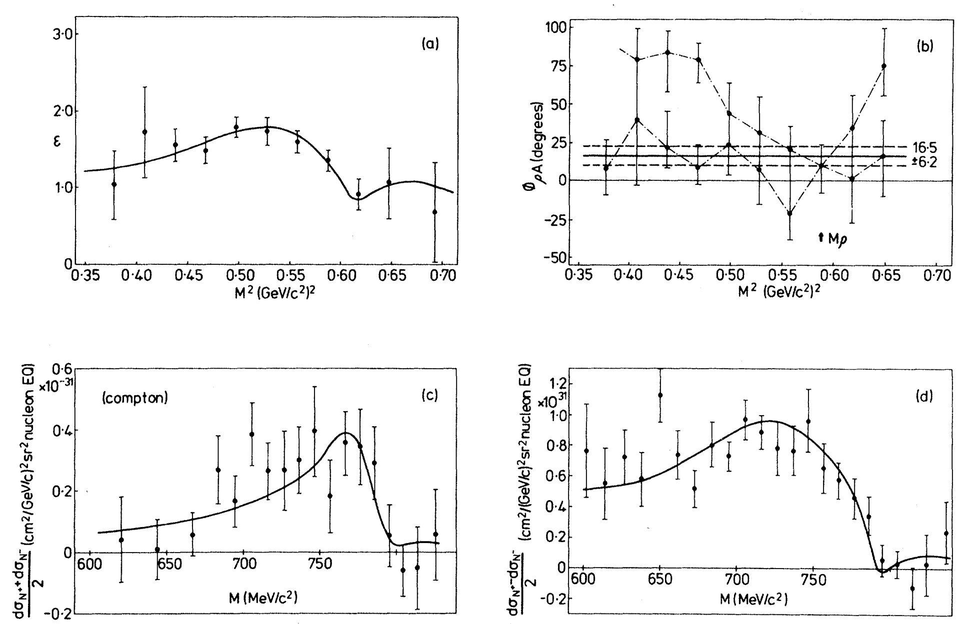

FIG. 2. (a) The asymmetry parameter ϵ as a function of m^2. (b) The values of the phase $\varphi_{\rho A}$ obtained by fitting the individual mass points $\epsilon(m^2)$. The origin of the double-valued solutions is discussed in the text. The differential cross section as a function of invariant pair mass for (c) the Compton process including ρ-ω interference and (d) the BH-Compton interference process. The solid curves are the best fit to the total mass spectrum in each case.

former combination was analyzed to obtain the ρ-ω interference parameters.[5] Fixing m_ρ, Γ_ρ^0, m_ω, and Γ_ω at the above best-fit values, and with a BH normalization of unity, the data were fitted [Fig. 2(c)] to give $\varphi_{\rho\omega}=115°\pm30°$ and $\gamma_\omega^2/\gamma_\rho^2=6.3\pm2.1$. These results are consistent with our previous values $\varphi_{\rho\omega}=100°{}^{+38°}_{-30°}$ and $\gamma_\omega^2/\gamma_\rho^2=7.0^{+2.1}_{-1.5}$, and may be compared with the values $\varphi_{\rho\omega}=41°\pm20°$ and $\gamma_\omega^2/\gamma_\rho^2=9.4^{+2.6}_{-1.6}$ obtained at $K=5$ GeV elsewhere.[13] The phase is in agreement with the value $118°{}^{+13°}_{-22°}$ obtained using $\epsilon(m^2)$.

The combination $(d\sigma_{N^+}-d\sigma_{N^-})/2$ was fitted using the same fixed parameters and in addition[9] with $\gamma_\omega^2/\gamma_\rho^2=7.0$, $\gamma_\rho^2/4\pi=0.50$, and $[d\sigma_{VA}/dt]_{t=0}=0.98$ mb GeV^{-2} nucleon^{-1}. The resultant phase angles were $\varphi_{\rho A}=14.1°{}^{+5.9°}_{-5.5°}$, $\varphi_{\rho\omega}=95°\pm13°$, and the fit is given in Fig. 2(d).

A measurement of the interference of the Coulomb and nuclear amplitudes in $\pi^\pm N$ forward scattering[14] has obtained values of $\alpha_{\pi^\pm N}\sim-0.2$ which with the additive quark model and vector-meson dominance lead[15] to a value $\alpha_{\rho N}\simeq-0.2$. Two calculations of the ratio $\alpha_{\gamma N}$ have been made using photon-photon total cross-section data, obtaining the results[16,17] $\alpha_{\gamma N}=-0.32$ and -0.30 at $K=4$ GeV. Assuming ρ-meson dominance it follows that $\alpha_{\rho N}=\alpha_{\gamma N}$, and hence these may be considered as further estimates of $\alpha_{\rho N}$.

It is concluded that the photoproduction amplitude of the ρ meson can be understood in terms of vector-meson dominance, with the inclusion of a significant real part whose sign and magnitude are consistent with real parts occurring in hadron interactions. The large values obtained for $\varphi_{\rho\omega}$ are in agreement with the value obtained in our earlier symmetric pair experiment which was carried out under different kinematic conditions. Such a value of $\varphi_{\rho\omega}$ and the correspondingly large value of $\varphi_{\omega A}$ are not able to provide a value for $\varphi_{\omega N}$ by treating the effect due to the complex nucleus in the same manner as for the ρ meson. In fact, it is not possible to calculate a value of $\varphi_{\omega A}$ larger than 45° for carbon, as is also found elsewhere.[18,19] The difficulties of reconciling the large ρ-ω phase due to electron pairs with that obtained for pion pairs has already been discussed in detail.[20]

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Observation of a New $K_N(1760)$ in the $K\pi$ and $K\pi\pi$ Systems*

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A new K^* resonance which we denote $K_N(1760)$ is observed. Its mass is 1759 ± 10 MeV and its width 60 ± 20 MeV. We assign it to the natural-spin-parity series on the basis of 5-standard-deviation evidence for a $K\pi$ decay mode. Decays into $K^*(890)\pi$ and $K\rho$ with the same mass and width are observed with 4-standard-deviation significance. It is suggested that this state is the analog of the g meson. In addition, we see evidence for further high-mass structure.

In this Letter we report the observation of a new natural-parity K^* resonance whose mass of 1759 ± 10 MeV and favored spin and parity of 3^- suggest that it is the strange component of the g-meson octet.

We have studied 4030 and 558 events, respectively[1] (8 events/μb nucleon) of the charge-exchange reactions

$$K^+n \to K^+\pi^-p \tag{1}$$

and

$$K^+n \to K^0\pi^+\pi^-p \text{ (visible vee)} \tag{2}$$

at an incident momentum of 9 GeV/c in the Brookhaven National Laboratory 80-in. deuterium bubble chamber. The cross sections for the two reactions are 505 ± 20 and 210 ± 30 μb. In Reactions (1) and (2) all track ambiguities are eliminated if we require that the four-momentum transfer squared $|t|$ between the neutron and the proton be less than 1 GeV^2. With the imposition of such a momentum-transfer cut, 3580 and 505 events remain in Reactions (1) and (2), respectively. In addition, we have analyzed (from half the film) 394 events[2] for the final states $K^+\pi^-\pi^0p$ and $K^0\pi^+\pi^-p$ where the vee is not seen.

Figure 1(a) shows the $K\pi$ mass spectrum for Reaction (1). We have fitted this spectrum with a superposition of the Breit-Wigner distributions for the well-known $K^*(890)$ and $K_N(1420)$ as well as a fourth-order polynomial background. The resulting curve (solid line) describes the data