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Determination of the $\omega \to \pi^+\pi^-$ Decay Amplitude from Photoproduction*

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Interference between ρ^0 and ω photoproduced from carbon, aluminum, and lead has been studied in the 2π decay mode. The branching ratio $(\omega \to 2\pi)/(\omega \to 3\pi)$ is $2.8 \pm 0.6\%$. The phase difference between the decay amplitudes $\omega \to 2\pi$ and $\rho^0 \to 2\pi$ is $63° \pm 16°$.

The existence of the G-parity-nonconserving decay $\omega \to \pi^+\pi^-$ is by now well established.[1-4] However, the value of the branching ratio and the phase of the decay amplitude are poorly known. Most information to date comes from studies of interference between ω and ρ^0 decaying through the $\pi^+\pi^-$ channel. To get quantitative results from such studies, it is necessary to understand the mechanisms that produce the ρ^0 and ω. In particular, one must know the relative magnitude, relative phase, and degree of coherence of the production amplitudes. If the ρ^0 and ω are produced in hadronic interactions, such information is invariably lacking. On the other hand, the mechanisms for photoproduction of ρ^0 and ω mesons from complex nuclei are much better understood[5-6] and are favorable for interference experiments because the degree of coherence is high. e^+e^- colliding-beam studies[7] share these advantages, but so far have been limited by poor statistics.

We have studied the process $\gamma A \to \pi^+\pi^- A$ (where A is for carbon, aluminum, and lead), and observed ρ^0-ω interference. The experimental setup is shown in Fig. 1. A 9.4-GeV bremsstrahlung beam passes through a target, located in the center of a small magnet (normally off), and then buries itself in a tungsten and lead plug. Pion pairs produced in the target are deflected by the second, large magnet and then pass through a system of trigger counters F, M, and B and the wire spark chambers $S1$-$S6$. The particle trajectory after the magnet, along with the pointlike target volume, suffice to determine the particle's vector momentum and hence the invariant mass of the $\pi\pi$ pair.

If the counters indicate that a pair of particles has passed through the system, the chambers are fired, read (via magnetostrictive readouts) into an IBM 1800 computer, and written onto magnetic tape. Also read in is the magnetic field in the large magnet. Various checks are made on line, but the track reconstruction and subsequent analysis are performed off line.

The absolute mass scale was determined to $\pm 0.25\%$ by floating-wire measurements. The geometric detection efficiency was determined by Monte Carlo calculations. To extend the mass range covered, a small amount of data was taken with larger trigger counters and reduced magnetic fields. The mass resolution was determined by Monte Carlo calculations, adjusted slightly on the basis of the electron transverse-momentum distribution; the rms widths were ± 5.50

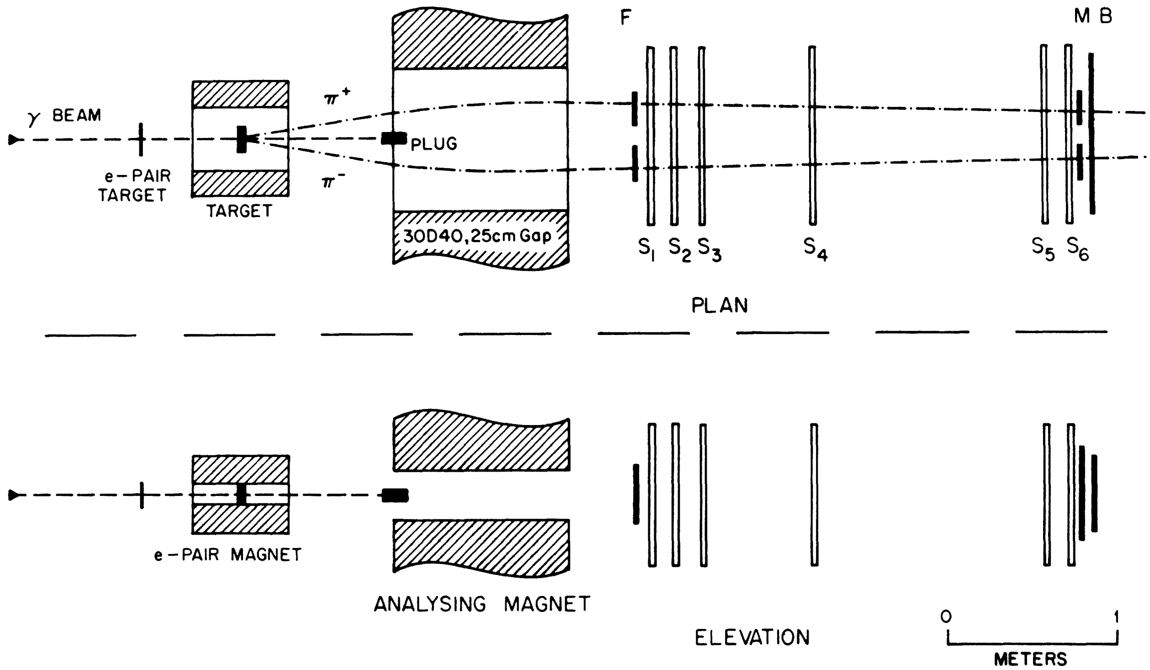

FIG. 1. Plan and elevation views of the experimental layout.

MeV for carbon, ±4.85 MeV for aluminum, and ±5.22 MeV for lead, and are believed accurate to ±6%.

The apparatus was tested with electron-positron pairs produced in a target just upstream of the small magnet. With the small magnet turned on, these particles acquire a constant[8] transverse momentum; specifically, (1) the transverse-momentum distribution has an rms width of 3.11 MeV, compared with 2.87 MeV predicted by Monte Carlo studies. As the resolution in transverse momentum is closely related to the mass resolution, this agreement provides a direct confirmation of the mass resolution. (2) The small magnet can be rotated about the beam line, sending electrons into different regions of the spark chambers. If the apparatus is free from distortions, the mean transverse momentum will be independent of this rotation angle. In fact, all points lie in a band of width ±0.1%. (3) $\overline{P}_x(E)$ and $\overline{P}_y(E)$, the mean horizontal and vertical components, respectively, of transverse momentum as a function of electron energy, are constant to ±0.25 MeV/c. Their ratio is in good agreement with the nominal rotation angle. Summarizing these tests, they show that the apparatus is free from systematic errors and that the Monte Carlo resolution studies are correct.

The reconstructed π-pair events were subjected to cuts on di-pion energy (between 7.0 and 9.15 GeV), production angle (in the first $1/e$ of the diffraction peak), and decay angle (symmetric decays, $|\cos\theta| < 0.2$). They were then corrected for apparatus-detection effeciency and extrapolated to zero momentum transfer using the optical model.[5a]

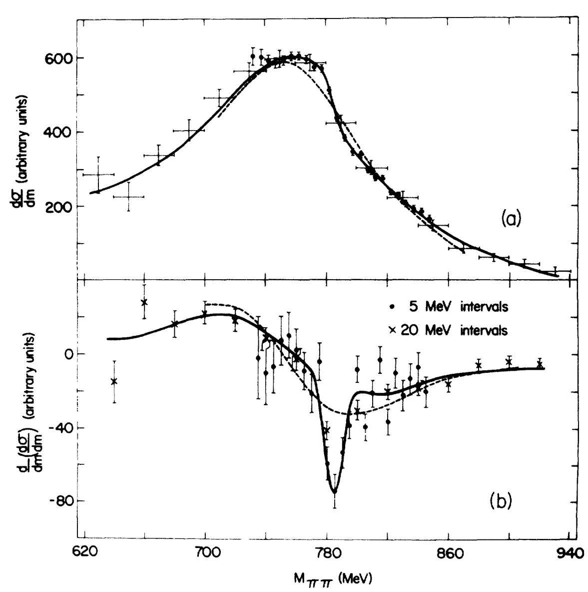

FIG. 2. (a) Mass spectrum and (b) first derivative of the mass spectrum of the π pairs photoproduced from carbon. The solid and dashed curves are fits with and without ρ^0-ω interference.

The mass spectrum for carbon is shown in Fig. 2(a). The ρ^0-ω interference shows up very clearly as a sharp drop near 780 MeV. This can be seen more easily in Fig. 2(b), where the first derivative of the mass spectrum is plotted. The ρ^0-ω interference now appears as a sharp dip. The aluminum and lead spectra show the same features, with slightly poorer statistical accuracy.

The following expression was used to fit the mass distributions:

$$\frac{d\sigma}{dm} = Km\Gamma_\rho(m)\left|\frac{(m_\rho/m)^2}{m^2-m_\rho^2+im_\rho\Gamma_\rho(m)}+\frac{\xi e^{i\varphi}}{m^2-m_\omega^2+im_\omega\Gamma_\omega}\right|^2+F_{\rm bg}(m). \quad (1)$$

This expression is a coherent sum of a Ross-Stodolsky–modified p-wave Breit-Wigner term with a Jackson-type width for the ρ^0 and a simple Breit-Wigner term for the ω. An incoherent polynomial background $F_{\rm bg}(m)$ is also included. The diffractive production of both ρ^0 and ω is well established; the small nondiffractive ω component will be incoherent with the ρ^0 and can be neglected.

Aside from the background term, which is quite small, there are two parameters, ξ and φ, which give, respectively, the relative magnitudes and relative phases of the ω and ρ^0 terms. Independent of any further assumptions, one has, for the nucleus A,

$$\xi_A^{\,2} = \frac{\sigma_{\gamma A\to\omega A}}{\sigma_{\gamma A\to\rho A}}\frac{\Gamma_{\omega\to2\pi}}{\Gamma_{\rho\to2\pi}}\frac{m_\rho}{m_\omega}. \quad (2)$$

We have previously measured[5,6] the cross-section ratio. If we make the vector-dominance assumption, then

$$\varphi_A = \Delta\varphi(\gamma\text{-}V \text{ coupling}) + \Delta\varphi(VA\to VA \text{ scattering}) + \Delta\varphi(V\to\pi^+\pi^-), \quad (3)$$

where all $\Delta\varphi$'s are phase differences between $V=\omega$ and $V=\rho^0$ for the processes indicated in parentheses.

We have tried many fits and find the following:

(1) The results are insensitive to variations in the data cuts.

(2) We fitted data in the mass range where the efficiency is >50% of the maximum efficiency, typically from 640 to 920 MeV. However, the fit does not deteriorate and the fitting parameters change negligibly if a broader mass range is included.

(3) The absolute mass scale was checked by varying the ω mass and comparing with the accepted value. The result, accurate to ±0.25%, differs from the floating-wire measurement by 0.15%. A variation of ±0.25% in the absolute mass scale changes φ by ±13° and ξ by ±3%, independent of A. For subsequent studies the ω mass was held fixed; the above-mentioned variations are included in the final errors.

(4) Letting the ρ^0 width be free, we find $\Gamma_\rho = 160 \pm 15$ MeV, independent of A. All other parameters are insensitive to the value of Γ_ρ. For subsequent studies, Γ_ρ was held fixed at 145 MeV as suggested by other experiments.[4,5]

(5) Varying the mass resolution, or (equivalently) the ω width, affects the determination of ξ, but not that of φ. Variations of 10% in resolution cause 5% variations in ξ. Thus, accurate knowledge of the resolution is important.

(6) We have investigated the model dependence of our results by modifying Eq. (1) in various ways: (i) multiplying the ω Breit-Wigner term by a Ross-Stodolsky factor; (ii) multiplying the enitre expression by m/m_ρ; (iii) removing the Ross-Stodolsky factor from the ρ^0 Breit-Wigner term and adding coherently a real constant (simplified Söding model). These modifications change ξ by ±2.5% and φ by ±5°, at most.

Results of two sets of fits are given in Table I. Errors are statistical only. In one fit, the ρ^0 mass was fixed at 770 MeV; in the other, it was free. The mass displays a small A dependence, which has little effect on ξ or φ. Both sets of fits are statistically acceptable. While the A dependence of m_ρ is not understood, it is not unreasonable. As A increases, the ρ^0 spends more of its time in nuclear matter, and the probability that it decays before leaving the nucleus increases. Also, the 2π background, which de-

Table I. Results of two sets of fits, either fixing m_ρ at 770 MeV or leaving it as an adjustable parameter.

	Carbon	Aluminum	Lead
m_ρ (MeV)	770	770	770
$\xi \times 10^2$	1.34 ± 0.12	1.35 ± 0.16	1.45 ± 0.19
φ (deg)	94.7 ± 4.5	79.4 ± 5.2	77.8 ± 6.0
m_ρ (MeV)	767.6 ± 1.4	771.1 ± 1.8	771.8 ± 1.7
$\xi \times 10^2$	1.24 ± 0.12	1.38 ± 0.18	1.51 ± 0.20
φ (deg)	92.4 ± 5.0	80.3 ± 5.6	81.2 ± 6.6

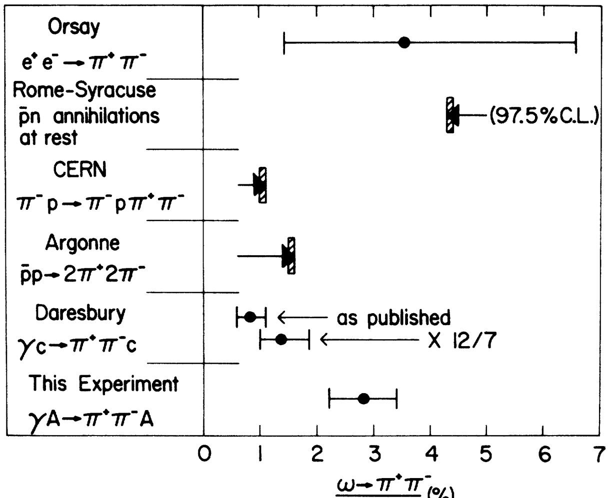

FIG. 3. Comparison of this measurement of the $(\omega \to 2\pi)/(\omega \to 3\pi)$ branching ratio with those of Orsay (Ref. 7), Rome-Syracuse (Ref. 9), CERN (Ref. 3), Argonne (Ref. 2), and Daresbury (Ref. 4). Upper and lower limits are at the 97.5% confidence level.

pends on A, might simulate a small mass shift. Either effect might cause a shift as large as that observed: $\Delta m_\rho/\Gamma_\rho \approx 0.03$.

Within statistical accuracy, ξ_A is independent of A. Using Eq. (2) and the results of our previous experiments,[5a,6] we find $(\Gamma_\omega \to \pi^+\pi^-)/(\Gamma_\omega \to \pi^+\pi^-\pi^0) = (2.8 \pm 0.6)\%$. The error includes systematic and model-dependent effects, which are small. Results from several experiments,[2-4,7,9] are shown in Fig. 3. Our result is consistent with, and more accurate than, all other results except those of the Daresbury group.[4] Part of the discrepancy is removed if their data are reanalyzed using the cross-section ratio (12) from our previous experiments,[5,6] rather than their value (7), determined less directly from a leptonic-decay interference experiment.[10]

From Eq. (3), one sees that it is necessary to know the phase difference in V-nucleus scattering and the phase difference in γ-V coupling in order to extract the phase difference of the $V \to 2\pi$ decay amplitudes. The latter is taken as $11°$ from a calculation by Gourdin.[11] The former we obtain from an optical-model calculation[5a,6] using[12] $\tan^{-1}\alpha_\omega - \tan^{-1}\alpha_\rho = -17° \pm 17°$, $\alpha_\rho = -0.24$, $\sigma_{\omega N} = 25.3 \pm 7.8$ mb, and $\sigma_{\rho N} = 27$ mb. The calculated V-nucleus phase differences are $12° \pm 13°$ (carbon), $11° \pm 12°$ (aluminum), and $7° \pm 6°$ (lead). These lead to a value of $63° \pm 16°$ for $\varphi(\omega \to \pi^+\pi^-) - \varphi(\rho^0 \to \pi^+\pi^-)$. The error comes principally from the 0.25% uncertainty in the absolute mass scale. This result disagrees with the Orsay[7] value ($153° \pm 28°$), and with a calculation of Gourdin[11] ($101° \pm 6°$).

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