SLAC – PUB – 3681
May 1985
(T/E)

Observation of J/ψ Radiative Decay to Pseudoscalar $\omega\omega$ *

R.M. Baltrusaitis, J.J. Becker, G.T. Blaylock, J.S. Brown, K.O. Bunnell, T.H. Burnett, R.E. Cassell, D. Coffman, V. Cook, D.H. Coward, H. Cui, C. Del Papa, D.E. Dorfan, A.L. Duncan, K.F. Einsweiler, B.I. Eisenstein, R. Fabrizio, G. Gladding, F. Grancagnolo, R.P. Hamilton, J. Hauser, C.A. Heusch, D.G. Hitlin, L. Köpke, P.M. Mockett, L. Moss, R.F. Mozley, A. Nappi, A. Odian, R. Partridge, J. Perrier, S.A. Plaetzer, J.D. Richman, J.R. Roehrig, J.J. Russell, H.F.W. Sadrozinski, M. Scarlatella, T.L. Schalk, R.H. Schindler, A. Seiden, J.C. Sleeman, A.L. Spadafora, J.J. Thaler, W. Toki, Y. Unno, F. Villa, A. Wattenberg, N. Wermes, H.J. Willutzki, D. Wisinski, W.J. Wisniewski

The MARK III Collaboration

California Institute of Technology, Pasadena, CA 91125
University of California at Santa Cruz, Santa Cruz, CA 95064
University of Illinois at Urbana-Champaign, Urbana, IL 61801
Stanford Linear Accelerator Center, Stanford, CA 94305
University of Washington, Seattle, WA 98195

ABSTRACT

We present evidence for the radiative decay $J/\psi \to \gamma\omega\omega$ with a branching fraction of $(1.76\pm0.09\pm0.45)\times10^{-3}$. The $\omega\omega$ invariant mass distribution peaks at 1.8 GeV/c^2, just above threshold. Analysis of angular correlations indicates that the $\omega\omega$ system below 2 GeV/c^2 is predominantly pseudoscalar. Upper limits are presented for the branching fractions of $\omega\omega$ decays of the $\theta(1690)$, the g_T states near 2.2 GeV/c^2, and the η_c.

Submitted to *Physical Review Letters*

*Work supported in part by the Department of Energy, contract numbers DE–AC03–76SF00515, DE–AC02–76ER01195, DE–AC03–81ER40050, DE–AM03–76SF00034, and by the National Science Foundation.

Final states of two vector particles have been intensively studied for signatures of gluonic bound states in the mass region below 3 GeV/c^2. Enhancements in $\rho\rho$ final states have been seen in hadronic interactions,[1] photon-photon collisions,[2] and in radiative decays of the J/ψ.[3] In $\pi^- p$ scattering resonant behavior is observed near threshold in $\phi\phi$ final states.[4] These structures may be bound states of quarks and gluons such as $q\bar{q}$, $qq\bar{q}\bar{q}$, $q\bar{q}g$ or gg. Models for some of these hypotheses also predict specific cross sections and rates for decays to $\omega\omega$,[5] although this final state has not previously been observed.

We report a measurement of the branching ratio of the decay $J/\psi \rightarrow \gamma\omega\omega$, $\omega \rightarrow \pi^+\pi^-\pi^\circ$, and a spin–parity analysis of the $\omega\omega$ system, based on a sample of $(2.71 \pm 0.16) \times 10^6$ produced J/ψ's obtained with the Mark III detector[6] at SPEAR. For this analysis the central drift chamber, which measures momenta of charged tracks with a resolution σ_p/p of 2% at 1 GeV/c over 84% of the solid angle, and the electromagnetic shower counters are used. The shower counters cover 94% of the solid angle and detect photons with an energy resolution σ_E/E of $17\%/\sqrt{E(GeV)}$ and with 100% detection efficiency for energies greater than 100 MeV.

Events of the type $J/\psi \rightarrow \gamma + 2(\pi^+\pi^-\pi^\circ)$ are selected by requiring exactly four charged particles in the drift chamber with zero total charge. Events are also required to have between 5 and 7 detected showers with energies greater then 10 MeV. These showers are required to be outside a cone with half-angle 18° around charged particles, in order to reduce the number of spurious low energy photons produced by secondary hadronic interactions. Six constraint kinematic fits to the hypothesis $J/\psi \rightarrow \gamma + 2(\pi^+\pi^-\pi^\circ)$ are then applied, trying all possible photon combinations. The combination with the best fit is retained, if the χ^2 probability is greater than 0.02. Fig. 1 shows the distribution of invariant $\pi^+\pi^-\pi^\circ$ masses with eight possible combinations per event. The dominant contribution to the ω signal comes from $J/\psi \to \omega\pi^+\pi^-\pi^\circ\pi^\circ$.

To further reduce the background, events with spurious photons are rejected if a fit to the background hypothesis $J/\psi \to 7\pi$ has a larger χ^2 probability than the fit to the signal hypothesis, or if the event contains one or more additional photons with detected energies greater than 80 MeV. To remove background events in which a π° is falsely reconstructed from a high energy photon and a second spurious shower, a cut $|(E_{\gamma_1} - E_{\gamma_2})/E_{\pi^\circ}| < 0.9$ is introduced for both π°'s. Finally, the cut on the χ^2 probability is increased from 0.02 to 0.15.

The four pairs of $\pi^+\pi^-\pi^\circ$ mass combinations per event are plotted in the 2–dimensional histogram of Fig. 2. A cluster of events is observed in which both three pion combinations have an invariant mass equal to m_ω. Because the processes $J/\psi \to \omega\omega$ and $J/\psi \to \pi^\circ\omega\omega$ are forbidden by C-invariance, the presence of two ω's is direct evidence for the radiative decay $J/\psi \to \gamma\omega\omega$. Fig. 3(a) shows the 6π invariant mass distribution for the 412 events in which at least one combination has both $\pi^+\pi^-\pi^\circ$ masses within 0.753–0.813 GeV/c^2. The distribution peaks at 1.8 GeV/c^2, and is approximately 0.250 GeV/c^2 wide.

An estimate of the background in Fig. 3(a) must consider sources from $J/\psi \to \gamma 6\pi$, $J/\psi \to 7\pi$, and $J/\psi \to \omega 4\pi$. There is also background from the signal process itself when a photon from a π° decay is undetected, but the event is retained in the sample due to spurious showers. The contributions of these backgrounds to the events in Fig. 3(a) are estimated by extrapolation from the ω sidebands into the $\omega\omega$ signal area of Fig. 2. The ω sidebands are defined by $0.723 < m_\omega < 0.753$ and $0.813 < m_\omega < 0.843$. The sum of all backgrounds accounts for $(35 \pm 7)\%$ of the events below 2 GeV/c^2. Since the background is largest at low $\omega\omega$ masses ($m_{\omega\omega}$), alternative methods have been employed to study the contributions of the individual background sources and to verify that the estimation of their magnitude is correct. The dominant contribution, $(22 \pm 6)\%$, comes from events which contain one real ω. The shaded band in Fig. 3(a) represents all backgrounds; its width reflects both statistical and systematic uncertainties. The purely combinatorial background from events containing more than one combination of pions in the $\omega\omega$ window, $(4.9 \pm 1.1)\%$, does not contribute to Fig. 3(a).

The $\gamma\omega\omega$ detection efficiency is $(5.3 \pm 1.1)\%$, independent of $m_{\omega\omega}$. This results in branching fractions of

$$B(J/\psi \to \gamma\omega\omega) = (1.76 \pm 0.09 \pm 0.45) \times 10^{-3} \quad \text{for} \quad m_{\omega\omega} < 3.1 \text{ GeV/c}^2, \text{ and}$$

$$B(J/\psi \to \gamma\omega\omega) = (1.22 \pm 0.07 \pm 0.31) \times 10^{-3} \quad \text{for} \quad m_{\omega\omega} < 2.0 \text{ GeV/c}^2.$$

The systematic error includes the uncertainty in the background subtraction. Variation of the photon acceptance cuts produces no significant change in the branching fractions. $B(J/\psi \to \gamma\omega\omega)$ as a function of $m_{\omega\omega}$ is shown in Fig. 3(b). The 3-body phase space distributions for $J/\psi \to \gamma\omega\omega$ for S-wave and P-wave $\omega\omega$ systems are also shown for comparison.

The $\omega\omega$ invariant mass distribution in the η_c mass region is shown in the insert of Fig. 3(a). The superimposed curve corresponds to the 90% confidence level upper limit of $B(\eta_c \to \omega\omega) < 3.1 \times 10^{-3}$ using[7] $B(J/\psi \to \gamma\eta_c) = (1.27 \pm 0.36) \times 10^{-2}$.

For the following spin-parity studies we require that only one of the four 6π permutations has both $\pi^+\pi^-\pi^0$ masses in the ω window ($0.753 < m_{3\pi} < 0.813$). This eliminates 5% of the events. For systems of two vector mesons the distribution of χ, the angle between the meson decay planes, provides a unique signature for spin and parity.[8] This distribution takes the form $dN/d\chi \propto 1 + \beta\cos(2\chi)$, where β is a constant which depends only on spin and parity and is independent of the polarization of the $\omega\omega$ system. β is zero for odd spin and non-zero for even spin. Its sign is the parity of the $\omega\omega$ system. For $J^P = 0^-$, where β is -1, $dN/d\chi \propto \sin^2\chi$ and the effect is maximal.

Figure 4 shows the χ distribution for a) $J/\psi \to \gamma\omega\omega$ with $m_{\omega\omega}$ less than 2 GeV/c^2, and b) events from the ω sidebands. The distributions for signal and background events are strikingly different, the signal indicating a large component with even spin and odd parity. The solid line in Fig. 4(a) is the result of a fit to $a+b\,\sin^2\chi$, which yields a $\sin^2\chi$ contribution for the $\gamma\omega\omega$ event candidates below 2 GeV/c^2 of (75 ± 16)%, when we correct for the presence of a flat background as indicated in the figure.

A multi-channel analysis of the $\omega\omega$ final state is performed allowing for six possible spin-parity contributions to the $\omega\omega$ system, $0^\pm$, $1^\pm$ and $2^\pm$, plus an isotropic contribution.[9] The following assumptions are made to restrict the number of parameters: a) only the lowest orbital angular momentum is considered for a given spin-parity, b) the ratios of helicity amplitudes $x = A_1/A_0$ and $y = A_2/A_0$, although free parameters in the fit, are assumed to be real,[10] and c) interference between amplitudes of different spin-parity channels is not considered.

The number of events contributing to each of the seven channels as determined by the fit is displayed in Fig. 5(a)-(g) as a function of $m_{\omega\omega}$. The distribution of background events, obtained by applying the same method to ω sideband events, is indicated by the dashed histogram lines. The dominant feature at masses below 2 GeV/c^2 appears in the 0^- channel, amounting to $(55 \pm 11)\%$ of the events, $\gamma\omega\omega$ plus background. This corresponds to $(85 \pm 19)\%$ of the $\gamma\omega\omega$ signal, since the background (35%) is found not to contribute to this channel. This is consistent with the result obtained by the χ angle analysis. Events from the sidebands largely populate the isotropic channel. We conclude that the $\omega\omega$ signal below 2 GeV/c^2 is predominantly 0^- spin–parity.

From the contributions to the 2^+ channel (Fig. 5(e)) we estimate the 90% confidence level upper limits for the 2^{++} meson $\theta(1690)$[11] and the tensor states observed in $\pi^- p \to \phi\phi n$ reactions:[4]

$$B(J/\psi \to \gamma\theta) \cdot B(\theta \to \omega\omega) < 2.4 \times 10^{-4}$$

$$B(J/\psi \to \gamma g_T) \cdot B(g_T \to \omega\omega) < 2.6 \times 10^{-4} \ .$$

Here g_T stands for the mass range 2.1 GeV/c^2 $\leq$ $m_{\omega\omega}$ $\leq$ 2.4 GeV/c^2.

In summary, we have observed the decay $J/\psi \to \gamma\omega\omega$, $\omega \to \pi^+\pi^-\pi^\circ$, in which the $\omega\omega$ system below 2 GeV/c^2 is found to be predominantly 0^- spin-parity. The $\omega\omega$ mass distribution peaks at 1.8 GeV/c^2, which may be the result of a combination of rising phase space and falling amplitude due to resonances below threshold, specifically the $\iota(1440)$.[12] An analysis to correlate this with similar behavior found in $J/\psi \to \gamma\rho\rho$[9] is in progress.

We wish to acknowledge the efforts of the SPEAR staff. One of us (N.W.) wishes to thank the Alexander von Humboldt Foundation for support.

References

1. A. Bettini *et al.*, Nuovo Cim. 42, 695 (1966);
   H. Braun *et al.*, Nucl. Phys. *B*30, 213 (1971).

2. R. Brandelik *et al.*, Phys. Lett. 97*B*, 448 (1980);
   M. Althoff *et al.*, Z. Phys. *C*16, 13 (1982);
   D. L. Burke *et al.*, Phys. Lett. 103*B*, 153 (1981);
   H. J. Behrend *et al.*, Z. Phys. *C*21, 205 (1984).

3. D. L. Burke *et al.*, Phys. Rev. Lett. 49, 632 (1982).

4. A. Etkin *et al.*, Phys. Rev. Lett. 49, 1620 (1982).

5. B. A. Li and K. F. Liu, Phys. Rev. *D*30, 613 (1984).

6. D. Bernstein *et al.*, Nucl. Inst. Meth. 226, 301 (1984).

7. R. Partridge *et al.*, Phys. Rev. Lett. 45, 1150 (1980).

8. N. P. Chang and C. T. Nelson, Phys. Rev. Lett. 40, 1617 (1978);
   T. L. Trueman *et al.*, Phys. Rev. *D*18, 3423 (1978);
   R. M. Baltrusaitis *et al.*, Phys. Rev. Lett. 52, 2126 (1984).

9. R. M. Baltrusaitis *et al.*, SLAC–PUB–3682, to be submitted to Phys. Rev. D, (1985).

10. This assumption is found to be well fulfilled for the decays $J/\psi \to \gamma f(1270)$, $f \to \pi^+\pi^-$ and $J/\psi \to \gamma f'(1515)$, $f' \to K^+K^-$; R. M. Baltrusaitis *et al.*, SLAC–PUB–3720, to be submitted to Phys. Rev. D, (1985).

11. C. Edwards *et al.*, Phys. Rev. Lett. 48, 458 (1982).

12. N. N. Achasov and G. N. Shestakov, Novosibirsk Preprint, TF-83-142, (1985)

Figure Captions

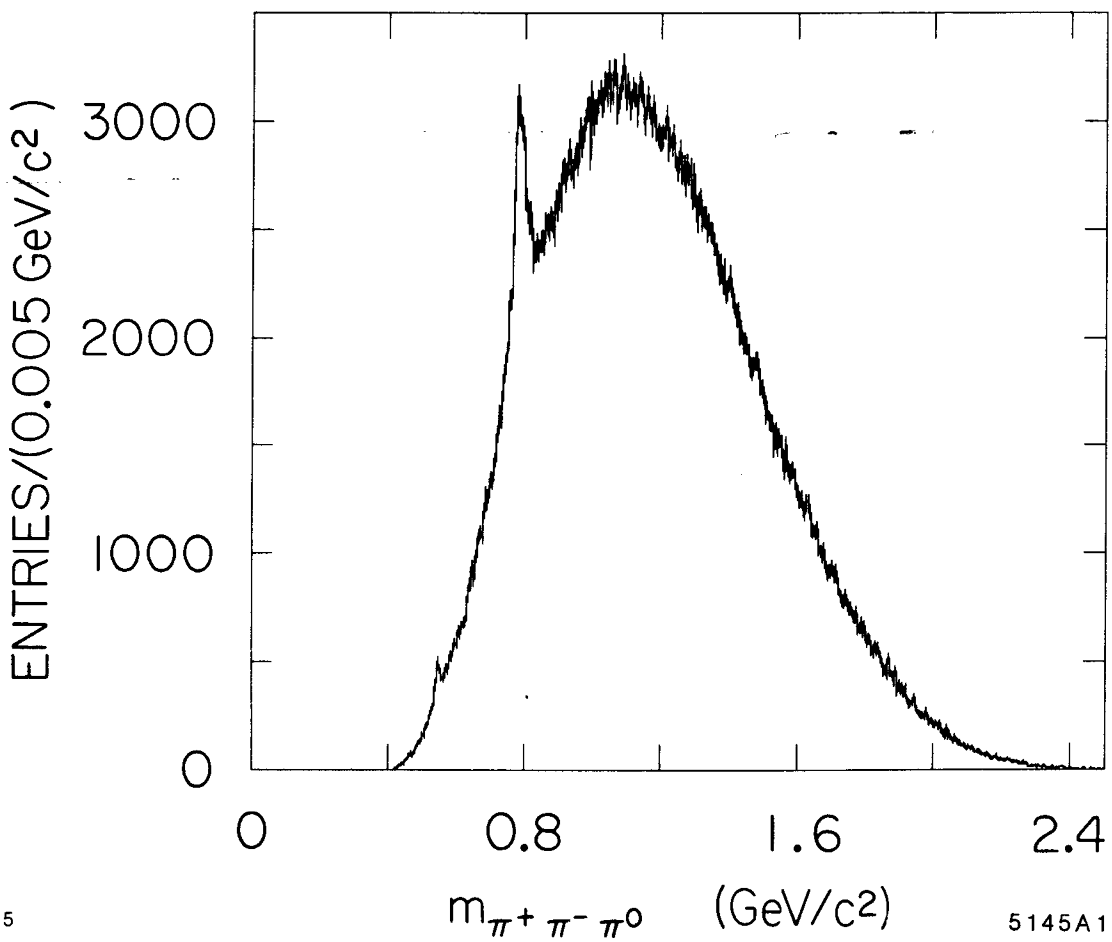
Fig. 1. Three pion invariant mass distributions (8 entries per event).

Fig. 2. $m_{\pi^+\pi^-\pi^\circ}$ versus $m_{\pi^+\pi^-\pi^\circ}$ of the recoiling three pion system (four entries per event).

Fig. 3. (a) $\omega\omega$ invariant mass distribution (one entry per event). The shaded band displays the background contribution. The insert shows the η_c mass region. (b) $B(J/\psi \rightarrow \gamma\omega\omega)$ as a function of $m_{\omega\omega}$. The errors include the uncertainty of the background subtraction, but not an overall systematic error of 16%. S-wave (dashed) and P-wave (dashed-dotted) phase space are indicated.

Fig. 4. Distribution of χ, the angle between the ω decay planes for (a) $m_{\omega\omega} < 2$ GeV/c^2 and (b) for ω sideband events. The curves are fits with $a + b \sin^2\chi$, and (b) a constant. The magnitude of a flat background is indicated by the band in (a).

Fig. 5. Results of the seven channel spin–parity analysis. The background contributions are indicated by the dashed histogram lines.



5-85

5145A1

Fig. 1

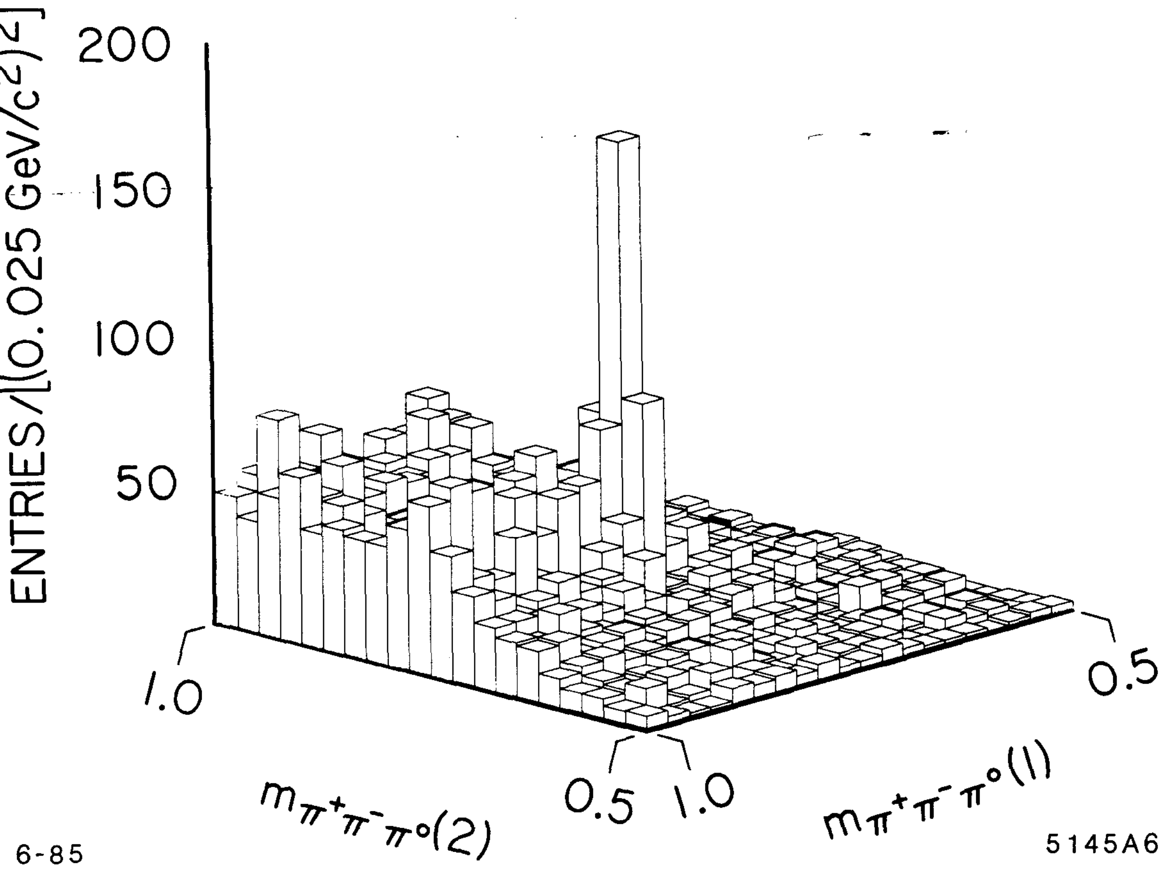
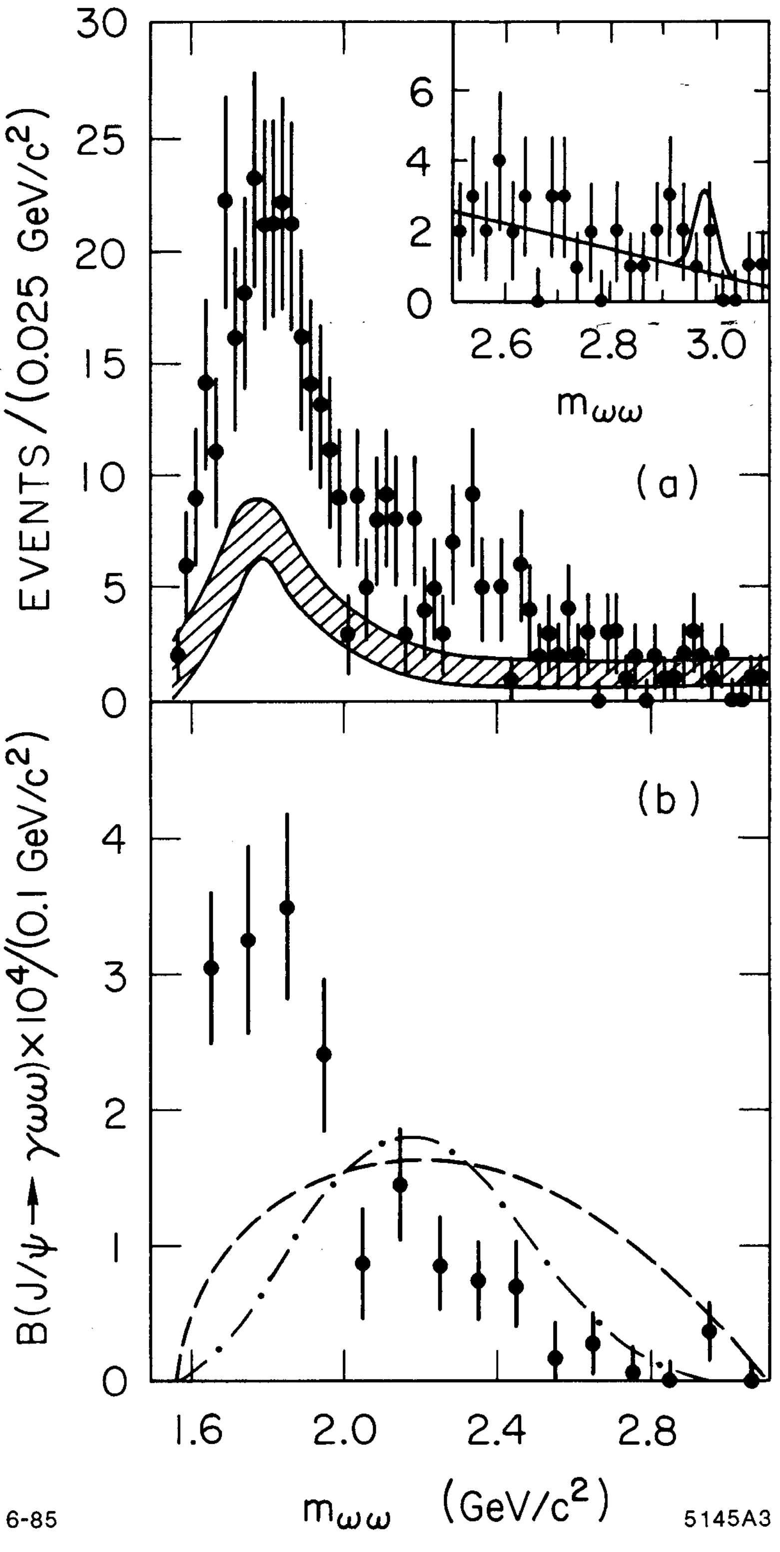
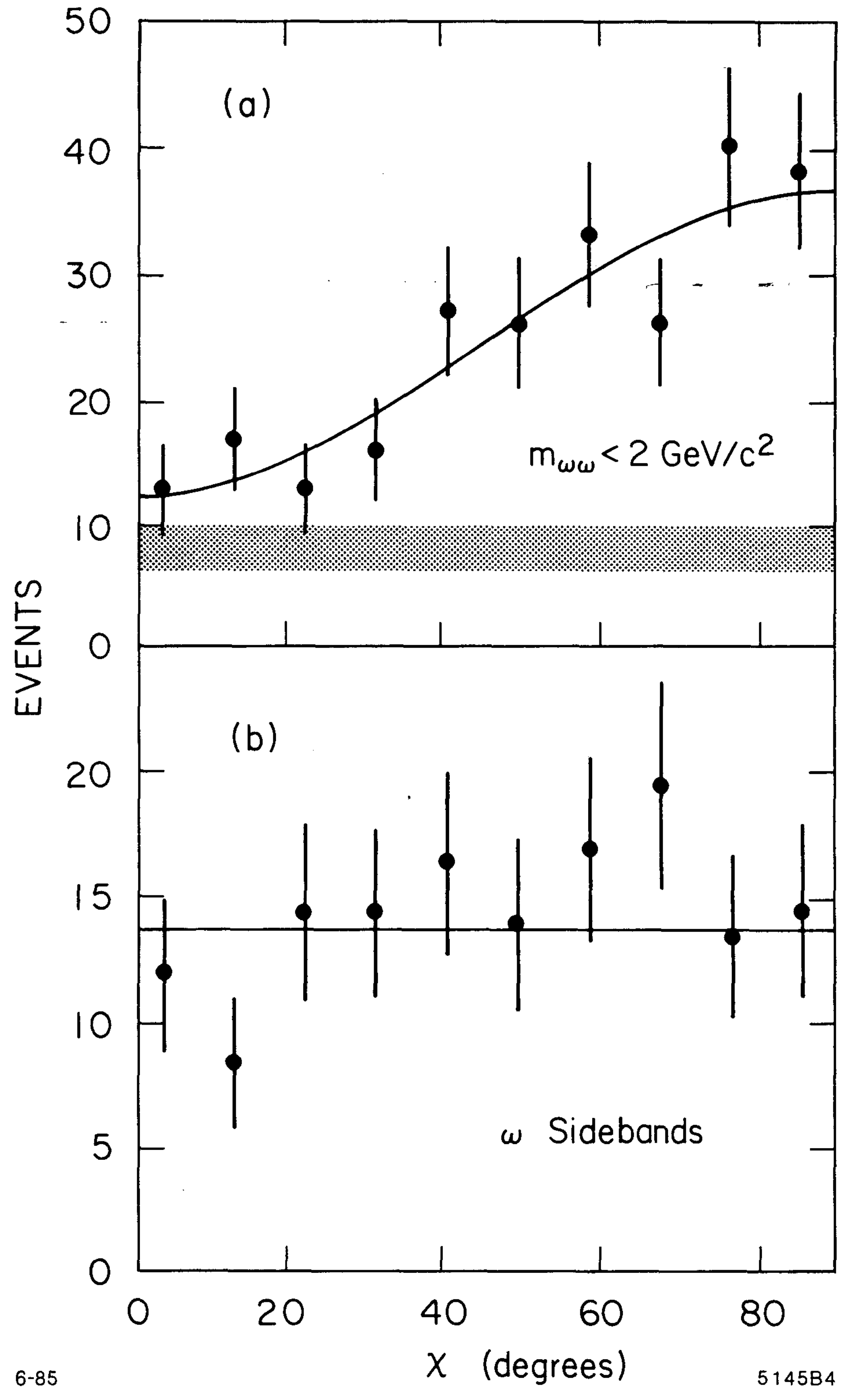

ENTRIES/[(0.025 GeV/c²)²]
200
150
100
50
1.0
0.5
0.5
1.0
mπ⁺π⁻π°(2)
mπ⁺π⁻π°(1)
6-85
5145A6

Fig. 2



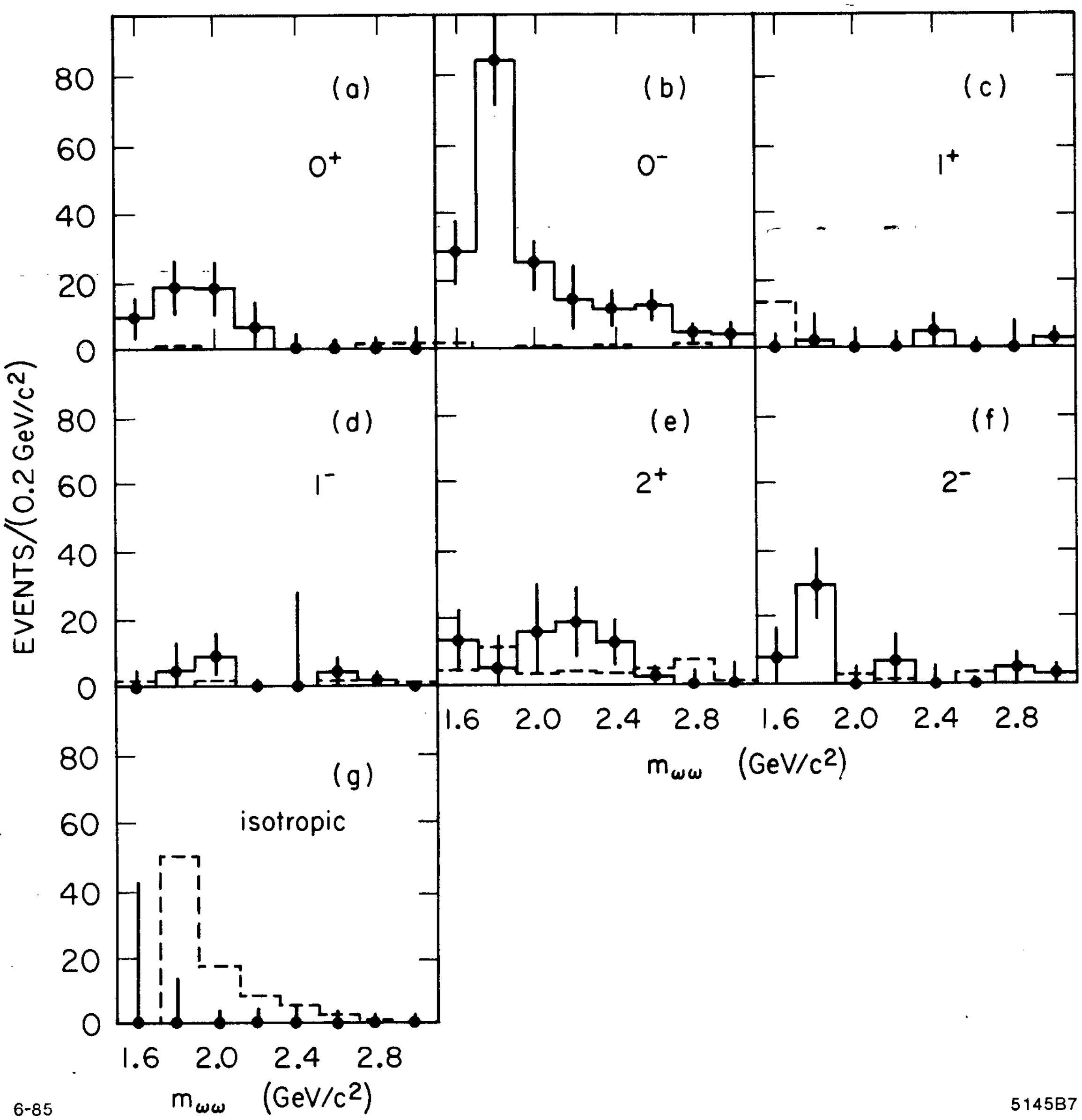
EVENTS / (0.025 GeV/c²)
(a)
$m_{\omega\omega}$
(b)
B(J/ψ → γωω)×10⁴/(0.1 GeV/c²)
$m_{\omega\omega}$ (GeV/c²)
6-85
5145A3

Fig. 3



50
40
30
20
10
0
(a)
$m_{\omega\omega} < 2$ GeV/c^2
EVENTS
(b)
20
15
10
5
0
ω Sidebands
0
20
40
60
80
χ (degrees)
6-85
5145B4

Fig. 4



(a)
0+
(b)
0-
(c)
1+
(d)
1-
(e)
2+
(f)
2-
(g)
isotropic
EVENTS/(0.2 GeV/c2)
80
60
40
20
0
1.6
2.0
2.4
2.8
mωω (GeV/c2)
6-85
5145B7

Fig. 5