Measurements of \( f_1(1285) \rightarrow \pi^+\pi^-\pi^+\pi^- \), \( \eta_c \rightarrow \rho^0\rho^0 \)
and \( \eta_c \rightarrow f_2(1270)f_2(1270) \) in Radiative \( J/\psi \) Decays

J. Adler, J.J. Becker, G.T. Blaylock, T. Bolton, J.C. Brient, J.S. Brown, K.O. Bunnell,
M. Burchell, T.H. Burnett, R.E. Cassell, D. Coffman, V. Cook, D.H. Coward, D.E. Dorfan,
C. Gatto, G. Gladding, C. Grab, R.P. Hamilton,† J. Hauser, C.A. Heusch, D.C. Hitlin, J.M. Izen,
L. Köpke, A. Li, W.S. Lockman, U. Mallik, C.G. Matthews, A. Mincer, R. Mir, P.M. Mockett,
K.F. Mozley, B. Nemati, A. Odian, L. Parrish, R. Partridge, D. Pitman, S.A. Plaetzer, J.D. Richman,
H.F.W. Sadrozinski, M. Scarlatella, T.L. Schalk, R.H. Schindler, A. Seiden, C. Simopoulos,
A.L. Spadafora, I.E. Stockdale, W. Stockhausen, W. Toki, B. Tripsas, F. Villa,
S. Wasserbaech, A. Wattenberg, A.J. Weinstein, N. Wermes, S. Weseler,
H.J. Willutski, D. Wisinski, W.J. Wsniewski, R. Xu, Y. Zhu

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
University of Iowa at Iowa City, IA 52242
Stanford Linear Accelerator Center, Stanford, CA 94309
University of Washington, Seattle, WA 98195

Abstract

A measurement of \( J/\psi \rightarrow \gamma\pi^+\pi^-\pi^+\pi^- \) is presented. The \( f_1(1285) \) is
observed and its spin and parity are investigated. The \( \eta_c \) is observed to
decay to \( \rho^0\rho^0 \), and the first observation of \( \eta_c \) decays to \( f_2(1270)f_2(1270) \)
is presented.

Submitted to the XXIV International Conference on High Energy Physics,
Munich, Germany, August 4–10, 1988

† This work was supported in part by the U. S. Department of Energy, under contracts
DE-AC03-76SF00515, DE-AC02-76ER01195, DE-AC03-81ER40050, DE-AM03-76SF0034,
and by the National Science Foundation.

‡ Deceased
The radiative decay $J/\psi \rightarrow \gamma \pi^+\pi^-\pi^+\pi^-$ has been studied previously by Mark III, with a smaller data sample. The present analysis is still in progress, and is therefore preliminary. Our data, taken with the Mark III detector at the SLAC $e^+e^-$ storage ring SPEAR, consist of $5.8 \times 10^6$ produced $J/\psi$'s. Events are selected with four charged tracks and one or more photon candidates. The events are kinematically fitted to the $J/\psi \rightarrow \gamma \pi^+\pi^-\pi^+\pi^-$ hypothesis, looping over all photon candidates (up to five, ordered in decreasing energy). The fit with the highest probability is kept. Selection criteria on kinematic quantities are imposed. The invariant mass distribution of the $\pi^+\pi^-\pi^+\pi^-$ system is shown in Figure 1a. A peak at 1.285 GeV/$c^2$ is seen, consistent with the $f_1(1285)$ mass and width. A prominent resonance at 2.98 GeV/$c^2$, consistent with the $\eta_c(2980)$ mass and width, is also seen. To study the first enhancement we look at the angular distributions for masses between 1.25 and 1.30 GeV/$c^2$. Figure 2a shows the distribution of $\chi$, the angle between the decay planes of the $\pi^+\pi^-$ systems in the $\pi^+\pi^-\pi^+\pi^-$ rest frame. This distribution is expected to be zero at $0^\circ$, rising to its maximum above $45^\circ$ if the $4\pi$ state has $J^P = 0^-$. In contrast for $J^P = 1^+$, this distribution is expected to be nearly flat. In Figure 2b the distribution of $\cos \theta_{\pi^+}$ is shown, where $\theta_{\pi^+}$ is the polar angle of the $\pi^+$ in the $\pi^+\pi^-$ rest frame. A $\sin^2 \theta_{\pi^+}$ distribution is expected if the $4\pi$ state has $J^P = 0^-$, while a nearly flat distribution is expected for $J^P = 1^+$. Our data rules out the pseudoscalar assignment, and is consistent with the $f_1(1285)$ being an axial vector. The branching ratio is given in Table I.

To study the $\eta_c$ region we select the invariant mass of the $\pi^+\pi^-\pi^+\pi^-$ system from 2.95 to 3.00 GeV/$c^2$, and plot one $\pi^+\pi^-$ invariant mass versus the other in Figure 3 (there are two entries for each event). An enhancement is seen in the $\rho^0\rho^0$ and $f_2(1270)$ $f_2(1270)$ regions. Such enhancements are not seen in nearby control regions of $M_{\pi^+\pi^-\pi^+\pi^-}$. Motivated by this, we define: $\delta_{\rho^0} = (M_{\pi^+\pi^-})_1 - 0.77)^2 + (M_{\pi^+\pi^-})_2 - 0.77)^2$ and $\delta_{f_2} = (M_{\pi^+\pi^-})_1 - 1.27)^2 + (M_{\pi^+\pi^-})_2 - 1.27)^2$. We restrict $\delta_{\rho^0} < 0.15$ and $\delta_{f_2} > 0.30$ GeV/$c^2$ and plot $M_{\pi^+\pi^-\pi^+\pi^-}$ in Figure 1b. A clear $\eta_c$ signal is seen. The angular distributions in the $\eta_c$ region are currently
being investigated. We restrict $\delta_{f_2} < 0.175$ and $\delta_{\rho^0} > 0.26$ GeV/$c^2$ and plot $M_{\pi^+\pi^-\pi^+\pi^-}$ in Figure 1c. A clear $\eta_c$ signal is seen providing the first evidence of a tensor-tensor decay of the $\eta_c$. The angular distributions in the $\eta_c$ region and the $f_2$ helicities are currently being studied. The branching ratios are given in Table I, where the first error is statistical and the second systematic.

Table I. $J/\psi \rightarrow \gamma\pi^+\pi^-\pi^+\pi^-$ Preliminary Branching Ratios.

<table>
<thead>
<tr>
<th>Process</th>
<th>Product branching ratio ($10^{-4}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$(J/\psi \rightarrow \gamma f_1(1285))(f_1 \rightarrow \pi^+\pi^-\pi^+\pi^-)$</td>
<td>$0.55 \pm 0.11 \pm 0.10$</td>
</tr>
<tr>
<td>$(J/\psi \rightarrow \gamma \eta_c)(\eta_c \rightarrow \pi^+\pi^-\pi^+\pi^-)$</td>
<td>$1.50 \pm 0.13 \pm 0.30$</td>
</tr>
<tr>
<td>$(J/\psi \rightarrow \gamma \eta_c)(\eta_c \rightarrow \rho^0\rho^0)$</td>
<td>$0.96 \pm 0.15 \pm 0.22$</td>
</tr>
<tr>
<td>$(J/\psi \rightarrow \gamma \eta_c)(\eta_c \rightarrow f_2(1270)f_2(1270))$</td>
<td>$1.2 \pm 0.3 \pm 0.4$</td>
</tr>
</tbody>
</table>

Conclusions

A measurement of $J/\psi \rightarrow \gamma\pi^+\pi^-\pi^+\pi^-$ is presented. The $f_1(1285)$ is observed and its spin and parity are found to be consistent with an axial vector. The $\eta_c$ is observed to decay to $\rho^0\rho^0$. The first observation of $\eta_c$ decays to $f_2f_2$ is presented.

References

FIGURE CAPTIONS

1. The $\pi^+\pi^-\pi^+\pi^-$ invariant mass distribution for events of the type: (a) $J/\psi \rightarrow \gamma \pi^+\pi^-\pi^+\pi^-$; (b) $J/\psi \rightarrow \gamma \rho^0\rho^0$, $\rho^0 \rightarrow \pi^+\pi^-$; (c) $J/\psi \rightarrow \gamma f_2(1270)f_2(1270)$, $f_2 \rightarrow \pi^+\pi^-$.

2. (a) $\chi$ and (b) $\cos \theta_{\pi^+}$ distributions for events of the type: $J/\psi \rightarrow \gamma f_1(1285)$; $f_1 \rightarrow \pi^+\pi^-\pi^+\pi^-$.

3. Scatter plot of $M_{\pi^+\pi^-}$ vs. $M_{\pi^+\pi^-}$ for events of the type $J/\psi \rightarrow \gamma \pi^+\pi^-\pi^+\pi^-$ where $2.95 < M_{\pi^+\pi^-\pi^+\pi^-} < 3.00$ GeV/$c^2$ ($\eta_c$ region).
Figure 1
Figure 2
Figure 3

$M_{\pi^+\pi^-}$ (GeV/c)$^2$