SLAC-PUB-5201
UWSEA PUB 90-1
November 1991
(T/E)

OBSERVATION OF $f_1(1285) \to \pi^+\pi^-\pi^+\pi^-$ IN RADIATIVE J/ψ DECAYS*

T. Bolton,[e,1] J. S. Brown,[f] K. O. Bunnell,[e] M. Burchell,[b,2] T. H. Burnett,[f] R. E. Cassell,[e] D. Coffman,[a,3] D. H. Coward,[e] F. DeJongh,[a,4] J. Drinkard,[b,5] G. P. Dubois,[a] G. Eigen,[a] B. I. Eisenstein,[c] T. Freese,[c,6] C. Gatto,[b,7] G. Gladding,[c] C. A. Heusch,[b] D. G. Hitlin,[a] J. M. Izen,[c,8] P. C. Kim,[e,3] J. Labs,[e] A. Li,[f] W. S. Lockman,[b] U. Mallik,[d] C. G. Matthews,[c] R. Mir,[f,9] P. M. Mockett,[f] A. Odian,[e] L. Parrish,[f] D. Pitman,[e,10] J. D. Richman,[a,11] H. F. W. Sadrozinski,[b] M. Scarlatella,[b] T. L. Schalk,[b] R. H. Schindler,[e] A. Seiden,[b] I. E. Stockdale,[c,12] W. Toki,[e] B. Tripsas,[c,13] M. Z. Wang,[d] A. J. Weinstein,[a] H. J. Willutzki,[f,14] W. J. Wisniewski,[a] R. Xu,[b,15] and Y. Zhu[a,16]

The Mark III Collaboration

[a] *Department of Physics, California Institute of Technology, Pasadena, CA 91125*

[b] *Santa Cruz Institute for Particle Physics, University of California, Santa Cruz, CA 95064*

[c] *Department of Physics, University of Illinois at Urbana-Champaign, Urbana, IL 61801*

[d] *Department of Physics, University of Iowa, Iowa City, IA 52242*

[e] *Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309*

[f] *Department of Physics, University of Washington, Seattle, WA 98195*

Submitted to *Physics Letters B.*

⋆ Work supported by Department of Energy contracts DE–AC03–76SF00515, DE–AC02–76ER01195, DE–AC02–87ER40318, DE–AC03–81ER40050, and DE–AM03–76SF00010; and by National Science Foundation contract PHY8822028.

[1] Present address: Columbia University, PO Box 137, Irvington, NY 10533

[2] Present address: PPE Division, CERN, 1211 Geneva 23, Switzerland

[3] Present address: Wilson Laboratory, Cornell University, Ithaca, NY 14853

[4] Present address: Fermilab, PO Box 500, Batavia, IL 60510

[5] Present address: Centre de Physique des Particules de Marseille, F-13288 Marseille, CEDEX 9, France

[6] Present address: Systems Control Technology, 2300 Geng Road, Palo Alto, CA 94303

[7] Present address: INFN, 80125 Napoli, Italy

[8] Present address: University of Texas, 2601 North Floyd Road, Richardson, TX 75083

[9] Present address: Indiana University, Bloomington, IN 47405

[10] Present address: University of Victoria, Victoria, BC V8W 3P6 Canada

[11] Present address: University of California at Santa Barbara, Santa Barbara, CA 93106

[12] Present address: NASA Ames Research Center, MS 258-6, Moffett Field, CA 94035

[13] Present address: Center for Naval Analyses, 4401 Ford Avenue, Alexandria, VA 22302

[14] Present address: Brookhaven National Laboratory, Upton, NY 11973

[15] Present address: Institute of High Energy Physics, Academica Sinica, PO Box 918, Beijing, People's Republic of China

[16] Present address: International Telephone and Teledata, Inc., PO Box 80160, Goleta, CA 93118

Abstract

We present an analysis of $J/\psi \to \gamma f_1(1285)$, $f_1(1285) \to \pi^+\pi^-\pi^+\pi^-$, using the Mark III detector at SPEAR, based on 5.8 x 10^6 produced J/ψ events. We measure $B(J/\psi \to \gamma f_1(1285), f_1(1285) \to \pi^+\pi^-\pi^+\pi^-)$ = (4.8 $\pm$ 1.3 $\pm$ 0.9) x 10^{-5}. We obtain a new measurement of the absolute branching ratio of $J/\psi \to \gamma f_1(1285)$. The mixing angle of the $f_1(1285)$ and the $f_1(1420)$ in the 1^{++} nonet is determined.

The observation of the $f_1(1285)$ in radiative J/ψ decays contributes to our understanding of the C = + axial-vector nonet. The rates of $J/\psi \rightarrow \gamma f_1(1285)$ and $J/\psi \rightarrow \gamma f_1(1420)$ are related to the degree of mixing in the axial-vector nonet [1,2]. The Mark III experiment has measured $J/\psi \rightarrow \gamma f_1(1285)$ in the $\eta\pi\pi$ [3], $K\overline{K}\pi$ [4], and $\gamma\rho$ [5] final states. We report herein the observation of $J/\psi \rightarrow \gamma f_1(1285)$ in the $\gamma\pi^+\pi^-\pi^+\pi^-$ final state. This completes the set of measurements of $J/\psi \rightarrow \gamma f_1(1285)$ in all known $f_1(1285)$ major decay modes [6].

The data sample consists of 5.8 x 10^6 J/ψ's, collected with the Mark III detector [7] at the SLAC e^+e^- storage ring SPEAR. Events are selected with four charged tracks of zero total charge and one to four neutral showers. Each charged track is required to satisfy $|\cos\theta| < 0.85$, where θ is the polar angle of the track with respect to the beam axis. The neutral showers are required to have a detected energy of at least 50 MeV, to be inside well modelled regions of the electromagnetic calorimeter [8] and to be outside a cone with half-angle 18° around any charged track. Four-constraint kinematic fits to the $J/\psi \rightarrow \gamma\pi^+\pi^-\pi^+\pi^-$ hypothesis are applied to the four charged tracks and each one of the neutral showers. The fit with the best probability, required to be greater than 5%, is retained. To suppress the $J/\psi \rightarrow \gamma K_s K_s$ background, events are rejected if both $\pi^+\pi^-$ pairs have $0.48 < M_{\pi^+\pi^-} < 0.52$ GeV.

The principal background to the $J/\psi \rightarrow \gamma\pi^+\pi^-\pi^+\pi^-$ decay is the copious $J/\psi \rightarrow \pi^0\pi^+\pi^-\pi^+\pi^-$ reaction. To suppress this background, events with $P_T^2(\gamma) >$ 0.0015 GeV^2 are removed, where $P_T^2(\gamma) = [2P_{miss}\sin(\delta/2)]^2$, P_{miss} is the momentum vector opposite to the $\pi^+\pi^-\pi^+\pi^-$ system and δ is the angle between P_{miss} and the observed radiative photon direction.

The $\pi^+\pi^-\pi^+\pi^-$ invariant mass distribution is shown in fig. 1. A clear enhancement is seen between 1.25 and 1.31 GeV, over a rapidly rising background. The background under this enhancement is mainly due to residual $J/\psi \rightarrow \pi^0\pi^+\pi^-\pi^+\pi^-$ events. To determine the resonance parameters, the $\pi^+\pi^-\pi^+\pi^-$ invariant mass distribution is fitted with a nonrelativistic Breit-Wigner line shape, convoluted with a Gaussian resolution function, and a background parametrized by an exponential function. The result of the fit is 56 $\pm$ 15 resonance events, and a resonance mass of (1.279 $\pm$ 0.005) GeV.

To-determine the spin and parity of the resonance, we study the angular distributions of its decays. There are two angles that are particularly sensitive to different spin-parity assignments [9]: χ, the angle between the planes defined by $\pi^+\pi^-$ pairs in the $\pi^+\pi^-\pi^+\pi^-$ center of mass; and θ_{π^+}, the angle between the π^+ in the $\pi^+\pi^-$ center of mass and the $\pi^+\pi^-$ direction. The χ and the cos θ_{π^+} distributions are shown in figs. 2(a) and 2(b) respectively, for events in the $f_1(1285)$ region ($1.25 < M_{\pi^+\pi^-\pi^+\pi^-} < 1.31$ GeV), after a background subtraction. The magnitude of the background is estimated from the fit to fig. 1, and its shape is estimated from the χ and cos θ_{π^+} distributions in nearby side bands ($1.175 < M_{\pi^+\pi^-\pi^+\pi^-} < 1.225$ and $1.335 < M_{\pi^+\pi^-\pi^+\pi^-} < 1.385$ GeV). The overlaid curves show the χ and cos θ_{π^+} Monte Carlo distributions [10] for a $J^P = 1^+$ or $J^P = 0^-$ $f_1(1285)$, including combinatorial effects and detector biases. The data agree with a $J^P = 1^+$ assignment for the resonance, identifying the resonance as the $f_1(1285)$.

The branching ratio of $J/\psi \rightarrow \gamma f_1(1285)$, $f_1(1285) \rightarrow \pi^+\pi^-\pi^+\pi^-$ is measured to be:

$$B(J/\psi \rightarrow \gamma f_1(1285), f_1(1285) \rightarrow \pi^+\pi^-\pi^+\pi^-) = (4.8 \pm 1.3 \pm 0.9) \times 10^{-5} \quad . \qquad (1)$$

The first error is the statistical error obtained from the fit. The second error is the systematic uncertainty obtained by adding in quadrature the error on the number

TABLE I. $J/\psi \to \gamma f_1$ branching ratios.

Reaction	Reference	Branching ratio (10^{-4})
$J/\psi \to \gamma f_1(1285)$, $f_1(1285) \to \pi\pi\pi\pi$	This paper	$1.44 \pm 0.39 \pm 0.27$
$J/\psi \to \gamma f_1(1285)$, $f_1(1285) \to \delta\pi$, $\delta \to \eta\pi$	3	$3.90 \pm 0.42 \pm 0.87$
$J/\psi \to \gamma f_1(1285)$, $f_1(1285) \to \delta\pi$, $\delta \to K\overline{K}$	12	$0.66 \pm 0.26 \pm 0.29$
$J/\psi \to \gamma f_1(1285)$, $f_1(1285) \to \gamma\rho^0$	5	$0.25 \pm 0.07 \pm 0.03$
$J/\psi \to \gamma f_1$ *(1285)*	This paper	$6.25 \pm 0.63 \pm 1.03$
$J/\psi \to \gamma f_1(1420)$	13	$8.7 \pm 1.4\ ^{+1.4}_{-1.1}$

of J/ψ events (8.5%), the Monte Carlo simulation (5%), the choice of fit background (12%) and variation of selection criteria (11%).

The Mark III measurements of the isospin corrected product branching ratios of $J/\psi \to \gamma f_1(1285)$, $f_1(1285) \to$ X are summarized in Table I. The Particle Data Group list no other major f_1(1285) decays [6]. Assuming the final states in rows 1 to 4 account for all f_1(1285) decays [11], we obtain the branching ratio of $J/\psi \to \gamma f_1$ (1285) (Table I, row 5), where common systematic errors have been removed. Our result for $B(J/\psi \to \gamma f_1(1285))$ is compatible with predictions from hard QCD calculations that include longitudinal gluons in the hadronization process [1]. Our result for $(B(f_1(1285) \to \pi\pi\pi\pi))/(B(f_1(1285) \to \eta\pi\pi))$ is $0.37 \pm 0.11 \pm 0.11$, while the PDG summary quotes 0.76 ± 0.16 for this ratio [6].

There are currently two candidates for the heavier partner of the $f_1(1285)$ in the 1^{++} nonet, the f_1(1420) and the $f_1(1530)$. The $f_1(1530)$ has not been observed in J/ψ decays. We have recently studied the decay $J/\psi \to \gamma K\overline{K}\pi$ [13], and measured a K^*K peak in the 1^{++} channel consistent with the $f_1(1420)$ resonance. By identifying this peak with the $f_1(1420)$ and assuming $B(f_1(1420) \rightarrow K^*K) = 1$, we obtain the branching ratio of $J/\psi \rightarrow \gamma f_1(1420)$ (Table I, row 6).

If the $f_1(1420)$ is the heavier partner of the $f_1(1285)$, we can define a mixing angle in the 1^{++} nonet, α, by [14]: $\tan^2 \alpha = f\,(B(J/\psi \rightarrow \gamma f_1(1420)))/(B(J/\psi \rightarrow \gamma f_1(1285)))$. The function f has the form [2] $(p^n_{f_1(1285)})/(p^n_{f_1(1420)})$, where $p_{f_1(1285)}$ ($p_{f_1(1420)}$) is the momentum of the $f_1(1285)$ ($f_1(1420)$) in the J/ψ rest frame. The parameter n has been varied from 1 to 5, and the effect is included in the systematic error on α. Using the results from Table I rows 5 and 6 we obtain $\alpha = (52.0 \pm 2.7 \pm 3.6)^\circ$.

Ideal mixing in the 1^{++} nonet corresponds to $\alpha = 35.3^\circ$. Our result shows that the $f_1(1285)$ and the $f_1(1420)$ are not ideally mixed, in agreement with results from two-photon interactions [15]. The axial vector mixing angle can be compared to the Gell-Mann-Okubo quadratic mass formula prediction [16], α_{quad}. Using the Particle Data Group's mass values for the $f_1(1285)$, $f_1(1420)$, $a_1(1260)$, $K_1(1270)$ and $K_1(1400)$ states [17], we obtain $\alpha_{quad} = (46 \pm 9)^\circ$, in agreement with the mixing angle determined from the radiative decay rates of the J/ψ to the 1^{++} isoscalar mesons.

To summarize, we have observed $f_1(1285)$ decays into $\pi^+\pi^-\pi^+\pi^-$ and measure: $B(J/\psi \rightarrow \gamma f_1(1285), f_1(1285) \rightarrow \pi^+\pi^-\pi^+\pi^-) = (4.8 \pm 1.3 \pm 0.9) \times 10^{-5}$. Using all other $f_1(1285)$ decaymodes measured by this experiment, we determine $B(J/\psi \rightarrow \gamma f_1(1285)) = (6.25 \pm 0.63 \pm 1.03) \times 10^{-4}$. The mixing angle of the $f_1(1285)$ and the $f_1(1420)$ in the 1^{++} nonet is calculated to be $(52.0 \pm 2.7 \pm 3.6)^\circ$.

We gratefully acknowledge the dedicated efforts of the SPEAR and Stanford Linear Accelerator operating staff. One of us (G.E.) wishes to thank the Heisenberg Foundation for support.

References

[1] J. G. Körner, J. H. Kühn, M. Krammer and H. Schneider, Nucl. Phys. **B229,** 115 (1983).

[2] A. Seiden, H. Sadrozinski, and H. Haber, Phys. Rev. D38, 824 (1988).

[3] T. Bolton et al., "Partial Wave Analysis of $J/\psi \rightarrow \gamma\eta\pi^+\pi^-$," SLAC-PUB-5632 (1991); submitted to Phys. Rev. Lett.

[4] J. Drinkard, Univ. of California Santa Cruz preprint SCIPP 90/04 (thesis), (1990) unpublished.

[5] D. Coffman et al., Phys. Rev. **D41, 2695** (1990).

[6] For a review see: Particle Data Group, J. J. Hernandez et al., Phys. Lett. **B239,** 1 (1990).

[7] D. Bernstein et al., Nucl. Instr. Meth. 226, 302 (1984).

[8] The polar angle of the photon with respect to the beam axis, θ, is required to satisfy: $-0.93 < \cos(\theta) < -0.83$ or $-0.78 < \cos(\theta) < -0.03$ or $0.03 < \cos(\theta) < 0.77$ or $0.84 < \cos(\theta) < 0.95$.

[9] N. P. Chang and C. T. Nelson, Phys. Rev. Lett. **40,** 1617 (1978); T. L. Trueman, Phys. Rev. **D18, 3423** (1978).

[10] The angular distributions of the $f_1(1285)$ decay to $\pi^+\pi^-\pi^+\pi^-$ are proportional to: $(1+\cos^2\theta_{\pi_1^+})(1+\cos^2\theta_{\pi_2^+})$ for $f_1(1285)$ with $J^P = 1^+$, assuming the $\pi^+\pi^-$ pairs are in a spin 1 state; $(1-\cos^2\theta_{\pi_1^+})(1-\cos^2\theta_{\pi_2^+})(1-\cos 2\chi)$ for $f_1(1285)$ with $J^P = 0^-$.

[11] The only other known decay mode of the $f_1(1285)$ is into $\gamma\phi$ with a negligible branching ratio of 0.1%. The $f_1(1285)$ decay into $\gamma\omega$ is yet another possibility. Even if $B(f_1(1285) \rightarrow \gamma\omega)$ is as large as $B(f_1(1285) \rightarrow \gamma\rho)$, it will have little effect on our results.

[12] The $B(J/\psi \rightarrow \gamma f_1(1285), f_1(1285) \rightarrow \delta\pi, \delta \rightarrow K\overline{K})$ is obtained from a fit of two incoherent nonrelativistic Breit-Wigner functions, representing the f_1 (1285) and the $f_1(1420)$, to the spin 1 intensity distribution of fig. 9.1(b) in ref. 4.

[13] Z. Bai et al., Phys. Rev. Lett. 65, 2507 (1990).

[14] Since the radiative decays of the J/ψ proceed mainly through two gluons, we expect the $f_1(1285)$ and the $f_1(1420)$ to couple to an SU(3) singlet.

[15] The-result from two photon collisions for α is $48° \pm 2$" or $56^{+6°}_{-4°}$, depending on the form factor used. For further details see: D. Caldwell, in Proceedings of the *BNL Workshop: Glueballs* 1988, Upton, NY, 1988, edited by S-U. Chung (AIP Conf. Proc. No. 185) (AIP, New York, 1989).

[16] See, for example, D. Perkins, *Introduction* to *High Energy Physics*, Addison Wesley (1987).

[17] The measured K_A–K_B mixing angle of $(41 \pm 4)°$ is taken from R. K. Carnegie et al., Phys. Lett. **68B**, 287 (1977).

Figure Captions

1. The $\pi^+\pi^-\pi^+\pi^-$ invariant mass distribution for events of the type $J/\psi \rightarrow \gamma\pi^+\pi^-\pi^+\pi^-$. T he curves show the fit results for the background $+f_1(1285)$ (solid), and the exponential background (dashed).

2. Decay angular distributions for the $f_1(1285)$ in the mass region ($1.25 < M_{\pi^+\pi^-\pi^+\pi^-} < 1.31$ GeV) following a background subtraction described in the text. The curves show the Monte Carlo expectation for a $J^P = 1^+ f_1(1285)$ (solid), and the Monte Carlo expectation for a $J^P = 0^- f_1(1285)$ (dashed). (a) χ (two entries per event) and (b) $\cos\theta_{\pi^+}$ (four entries per event).

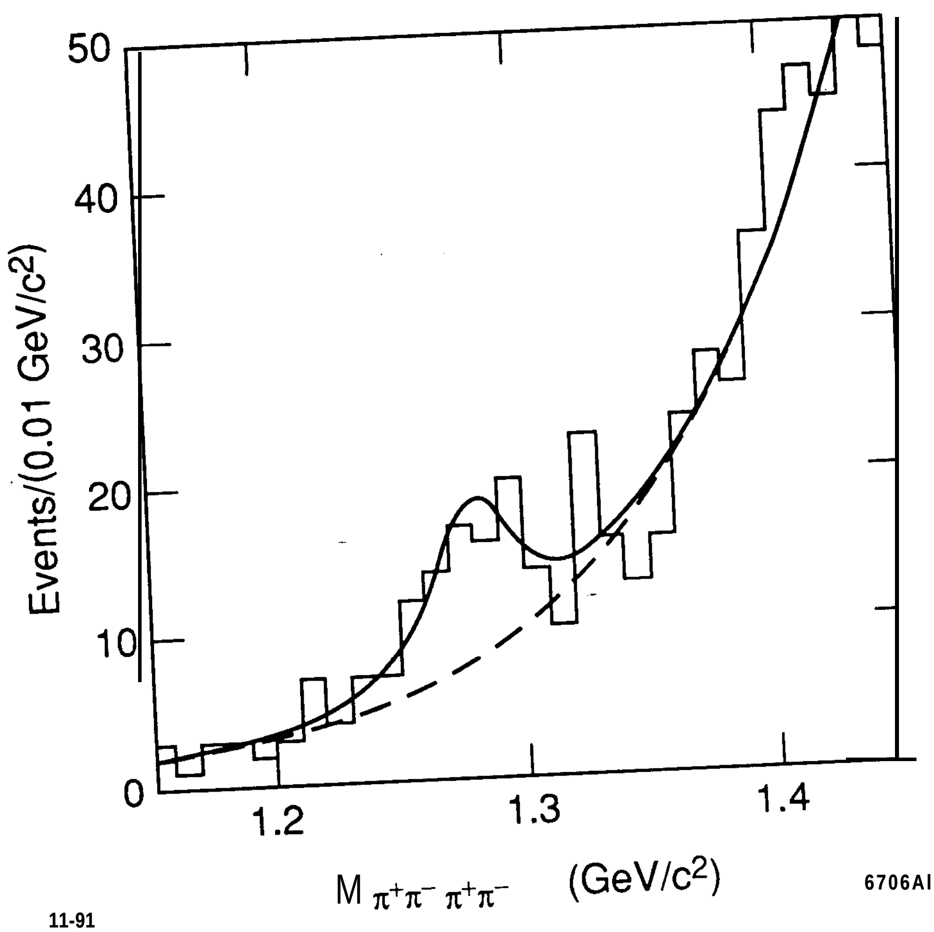
50
40
30
20
10
0
Events/(0.01 GeV/c2)
1.2
1.3
1.4
M π+π− π+π− (GeV/c2)
6706A1
11-91

Fig. 1

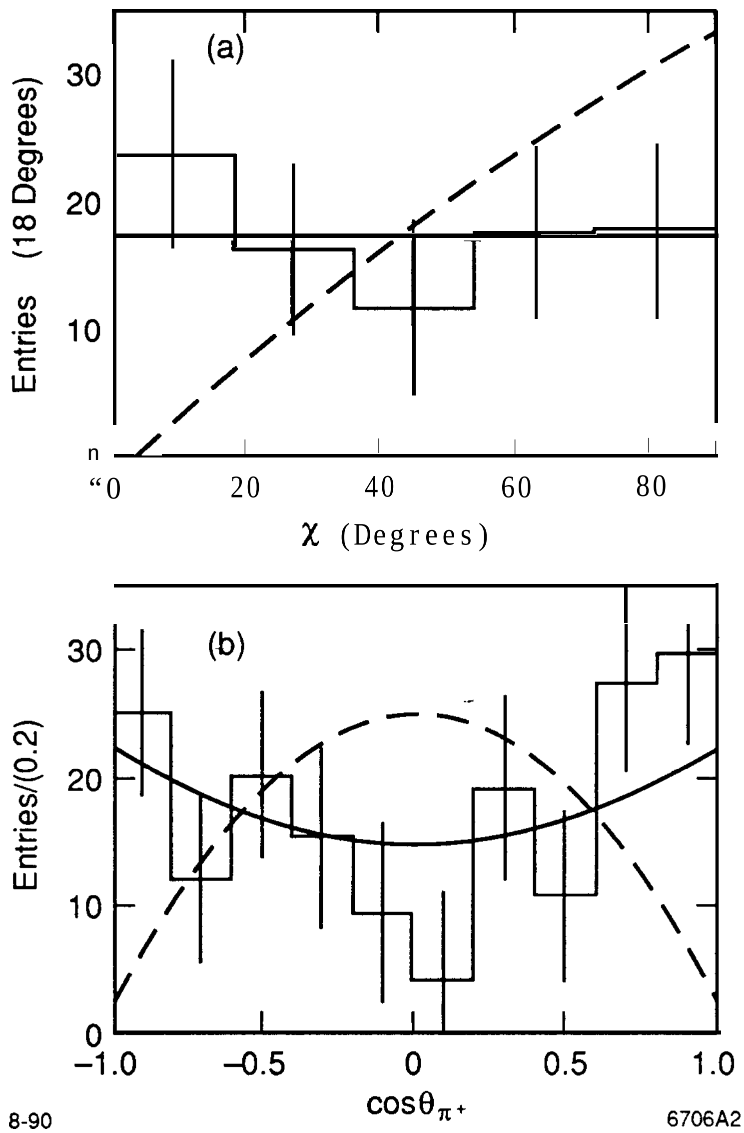
(a)
Entries (18 Degrees)
30
20
10
n
"0
20
40
60
80
χ (Degrees)
(b)
Entries/(0.2)
30
20
10
0
−1.0
−0.5
0
0.5
1.0
cosθπ+
8-90
6706A2

Fig. 2