

Observation of the Radiative Decay $J/\psi \rightarrow \gamma\phi\omega^*$

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ABSTRACT

The MARK III Collaboration has studied the OZI violating radiative decay $J/\psi \rightarrow \gamma\phi\omega$, in order to complete the set of measured $J/\psi \rightarrow \gamma$ vector vector decays. This channel is then used to search for a new decay mode of the $\xi(2230)$ and to study the η_c decay mechanism. The $\phi\omega$ mass spectrum does not show any significant structure; upper limits for the excitation of the ξ and η_c particles are obtained.

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Systems of two vector particles have been intensively studied for signatures of gluonic bound states. Pseudoscalar enhancements in $\rho\rho$ and $\omega\omega$ final states have been seen in radiative J/ψ decays;^[1] resonant $\phi\phi$ structures have been observed near threshold in πp scattering experiments.^[2] The study of $\eta_c(2980) \rightarrow 1^{--}1^{--}$ decays reveals a preference for final states with large s -quark contents,^[3] suggesting a similar pattern for gluonic bound states.^[4] The measurement of the $\eta_c \rightarrow \phi\omega$ decay rate can be used to determine the relative contributions of different η_c decay mechanisms.^[5] In addition, vector-vector decays of the $\xi(2230)$, a narrow state seen in $K\bar{K}$ final states,^[6] have been searched for. The OZI violating decay $\xi(2230) \rightarrow \phi\omega$ has been predicted if the ξ is a hybrid state.^[7]

We report on a measurement of the branching ratio of the decay $J/\psi \rightarrow \gamma\phi\omega$, $\phi \rightarrow K^+K^-$, $\omega \rightarrow \pi^+\pi^-\pi^0$, and upper limits for the excitation of the $\xi(2230)$ and $\eta_c(2980)$ resonances, based on a sample of 5.8×10^6 produced J/ψ 's obtained with the Mark III detector at the SLAC e^+e^- storage ring SPEAR.

For this analysis, the central drift chamber, measuring momenta of charged tracks with a resolution of $\delta p/p$ of 2% at 1 GeV/ c over 84% of the solid angle, a set of 48 axial time of flight (TOF) counters covering 80% 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 $\delta E/E$ of 17%/ $[E(\text{GeV})]^{1/2}$ and with 100% detection efficiency for energies greater than 0.1 GeV.

The $J/\psi \rightarrow \gamma\phi\omega \rightarrow \gamma K^+K^-\pi^+\pi^-\gamma\gamma$ events are initially selected by the requirement of exactly four charged particles with zero total charge. For at least one charged particle, it is required that measured and predicted time of flight differ by less than three standard deviations for the kaon mass hypothesis. Events are also required to have between three and six neutral showers with energies greater than 0.01 GeV. More than three showers are allowed, because spurious showers, associated with K -decays or hadrons interacting in the shower counters, are often observed.

Five constraint kinematic fits to the $J/\psi \rightarrow \gamma K^+K^-\pi^+\pi^-\pi^0$ hypothesis are

then applied, trying all possible photon combinations and particle type assignments. The best combination with regard to particle identification and kinematic fit χ^2 is retained, if the χ^2 probability is greater than 10%. The charged particle which is independently assigned to be a K^\pm by the kinematic fit is required to be incompatible with the predicted time of flight of a pion or proton if the particle enters the TOF system. To remove background in which a π^0 is falsely reconstructed from a high energy photon and a second spurious shower, a cut $|(E_{\gamma_1} - E_{\gamma_2})/P_{\pi^0}| < 0.90$ is applied to the photons forming the π^0 .

The $J/\psi \rightarrow \gamma K^+ K^- \omega$ events are further selected by requiring that the invariant $\pi^+ \pi^- \pi^0$ mass be within $0.03 \text{ GeV}/c^2$ of the nominal ω mass.¹⁶⁾ An estimate for the background of events not containing real ω 's is given by $0.06 \text{ GeV}/c^2$ wide sidebands centered $0.09 \text{ GeV}/c^2$ above and below the nominal ω mass. Figure 1 shows the invariant $K^+ K^-$ mass for signal events (a) and background events (b). Because the $J/\psi \rightarrow \phi \omega$ and $J/\psi \rightarrow \pi^0 \phi \omega$ reactions are forbidden by C-invariance, the 31 ± 5.6 observed $\phi \omega$ pairs present direct evidence for the radiative $J/\psi \rightarrow \gamma \phi \omega$ decay. Figure 2a shows the invariant $K^+ K^- \pi^+ \pi^- \pi^0$ mass distribution for events with $K^+ K^-$ invariant mass within $0.015 \text{ GeV}/c^2$ of the nominal ϕ mass and the $\pi^+ \pi^- \pi^0$ mass within $0.03 \text{ GeV}/c^2$ of the nominal ω mass. The estimate of the background, obtained from the ω sidebands defined above, is displayed in Fig. 2b. No significant structure is observed in the $1.7\text{--}3.1 \text{ GeV}/c^2$ mass range.

To obtain upper limits for the production of the $\xi(2230)$ and the $\eta_c(2980)$, fits to a flat background distribution and a gaussian resolution function are performed. The mass resolutions as determined by Monte Carlo simulations are $0.012 \pm 0.002 \text{ GeV}/c^2$ at $2.22 \text{ GeV}/c^2$ and $0.017 \pm 0.002 \text{ GeV}/c^2$ at $2.980 \text{ GeV}/c^2$. Assuming zero width the 90% upper limit for the excitation of the $\xi(2230)$ corresponds to 11 events. No event is observed in the η_c mass region corresponding to 2.3 events at 90% C.L.

The $J/\psi \rightarrow \gamma \phi \omega$ detection efficiency for the observed final state assum-

ing isotropic angular distributions^[9] are $(8.6 \pm 1.7)\%$ averaged over the 1.7–3.1 GeV/ c^2 mass range and $(9.1 \pm 1.8)\%$ at 2.22 GeV/ c^2 . The efficiency for the production of the pseudoscalar η_c is $(8.6 \pm 1.7)\%$. The errors include uncertainties due to event selection criteria, Monte Carlo handling of low energy photon showers, and flux determination. From the number of observed events and the flux of 5.8×10^6 produced J/ψ 's the branching fractions

$$B(J/\psi \rightarrow \gamma\phi\omega) = (1.40 \pm 0.25 \pm 0.28) \times 10^{-4}$$

$$B(J/\psi \rightarrow \gamma\xi) \cdot B(\xi \rightarrow \phi\omega) < 0.59 \times 10^{-4} \text{ @ } 90\% \text{ C.L.}$$

$$B(J/\psi \rightarrow \gamma\eta_c) \cdot B(\eta_c \rightarrow \phi\omega) < 0.13 \times 10^{-4} \text{ @ } 90\% \text{ C.L.}$$

are obtained after correcting for unobserved decay modes.

In summary, the OZI violating $J/\psi \rightarrow \gamma\phi\omega$ has been observed with no significant structure in the $\phi\omega$ mass distribution. With this measurement all decays of the η_c into pairs of vector mesons have been measured by the Mark III collaboration. This set can be used to determine the relative contributions of the mechanisms relevant to $\eta_c \rightarrow 1^{--}1^{--}$ decays. The measured η_c branching fractions to vector-vector final states, along with SU(3) predictions are summarized in Table 1.^[10] The observed decay pattern indicates that the $\eta_c \rightarrow 1^{--}1^{--}$ decay rate increases with the number of s -quarks in the final state, a SU(3)-breaking pattern very different from the one observed in $J/\psi \rightarrow 1^{--}0^{-+}$ decays.^[11] In order to understand this, one has to go beyond SU(3) symmetry considerations and has to discuss the dynamics of the decay. Figure 3 shows three mechanisms relevant to the $\eta_c \rightarrow 1^{--}1^{--}$ decays. The relative contributions can be determined using the measured decay rates: $\omega\phi$ can only arise from diagram (b), K^*K^* from diagrams (a) and (c), while $\rho\rho$, $\omega\omega$ and $\phi\phi$ can be produced by all three mechanisms.

Since the hadronization of the η_c proceeds largely through the 2-gluon intermediate state, the study of the η_c decay pattern should also further our understanding of gluonia decays.

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Table 1 . η_c branching fractions into vector-vector final states in percent; the reduced branching ratios ($\tilde{B}(\eta_c \rightarrow VV) \equiv B(\eta_c \rightarrow VV)/P_V^3$) and the SU(3) predictions are normalized to the $\phi\phi$ decay mode.

| Channel | B | \tilde{B} | SU(3) |
|----------------|-----------------|-----------------|-------|
| $\phi\phi$ | 0.40 ± 0.15 | 1 | 1 |
| K^*K^* | 0.9 ± 0.5 | 1.70 ± 0.95 | 4 |
| $\omega\phi$ | < 0.11 | < 0.20 | 0 |
| $\rho\rho$ | < 1.4 | < 2.15 | 3 |
| $\omega\omega$ | < 0.31 | < 0.48 | 1 |

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8. The three pion mass resolution at $0.78 \text{ GeV}/c^2$ is $0.012 \pm 0.003 \text{ GeV}/c^2$.
9. The Dalitz decay of the ω is correctly parametrized.
10. See reference 3. The value for the $\eta_c \rightarrow \phi\phi$ branching fraction is a weighted average of Mark III and DM2 measurements. The branching ratio $B(J/\psi \rightarrow \gamma \eta_c)$, used in the determination of $B(\eta_c \rightarrow X)$, contributes to a 28% systematic error common to all channels.
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Figure Captions

- Fig. 1. Invariant K^+K^- mass distribution from $J/\psi \rightarrow \gamma K^+K^-\pi^+\pi^-\pi^0$ reaction for (a) $\pi^+\pi^-\pi^0$ masses in ω signal region, or (b) ω sidebands.
- Fig. 2. Invariant $K^+K^-\pi^+\pi^-\pi^0$ mass distribution $J/\psi \rightarrow \gamma\phi\pi^+\pi^-\pi^0$ reaction for $\pi^+\pi^-\pi^0$ masses in ω signal region (upper plot) or ω sidebands (lower plot).
- Fig. 3. Various mechanisms for the η_c decay.

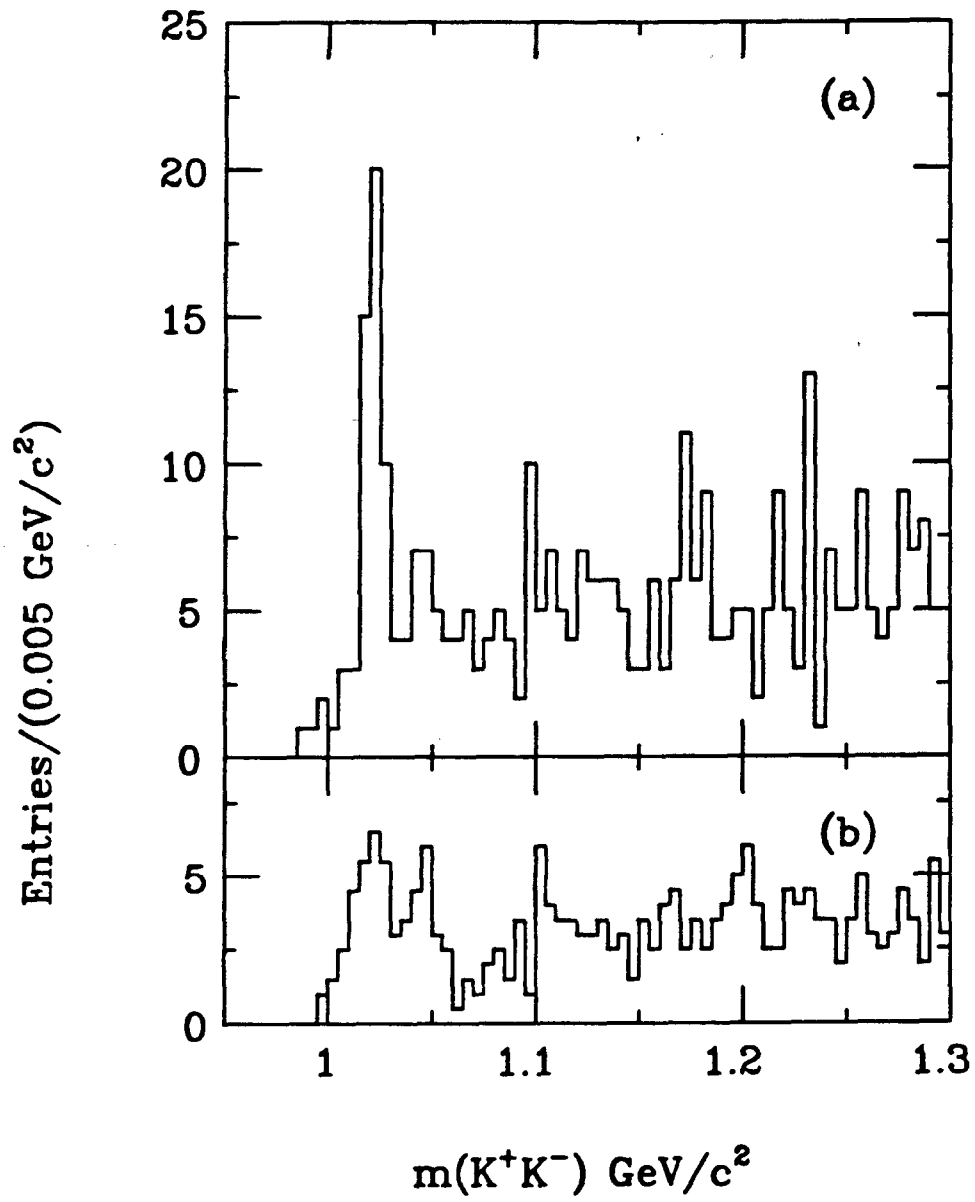


Fig. 1

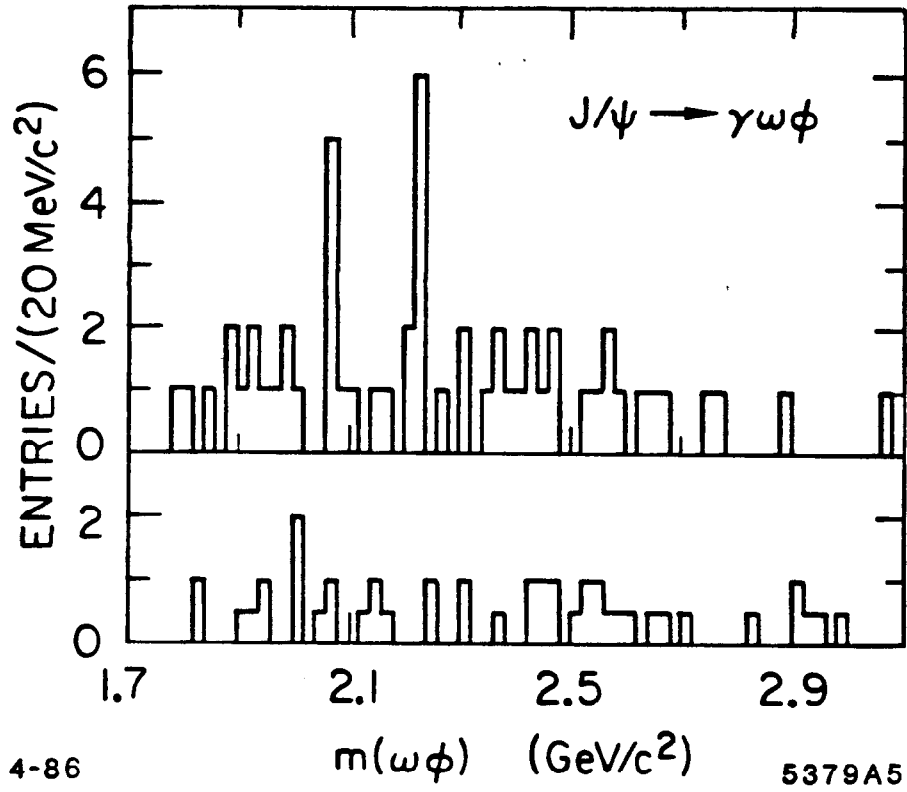


Fig. 2

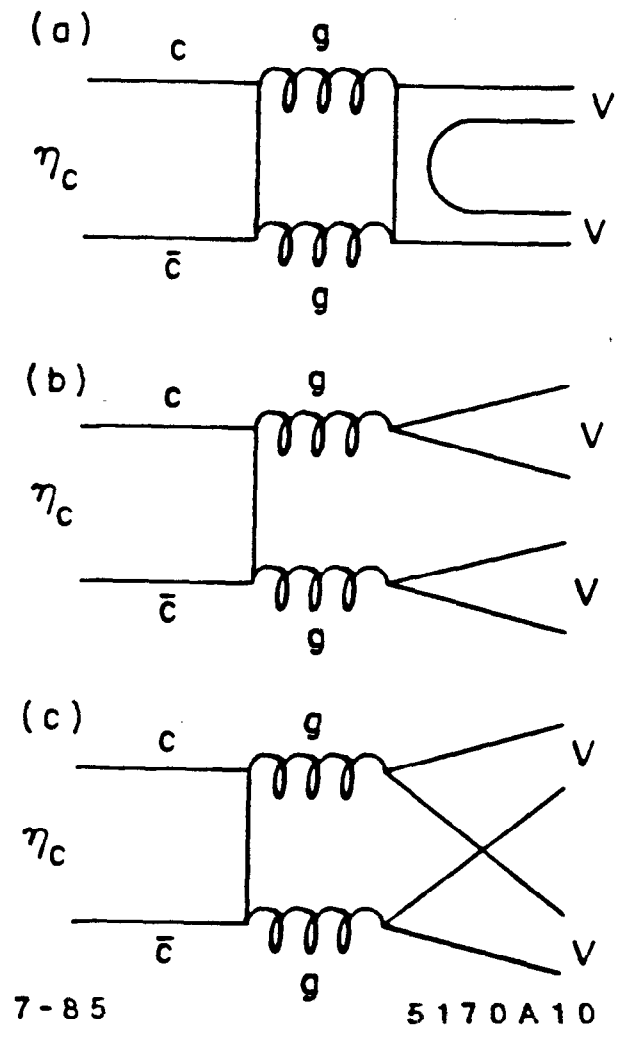


Fig. 3