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# MEASUREMENT OF THE $f^0(1270)$ POLARIZATION IN THE $J/\psi \rightarrow f^0\gamma$ DECAY

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# MEASUREMENT OF THE $f^0(1270)$ POLARIZATION IN THE $J/\psi \to f^0\gamma$ DECAY

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Abstract

The polarization of the $f^0(1270)$ and $\rho^0(770)$ produced in the $J/\psi$ decays into $f^0\gamma$ and $\rho^0\pi^0$ are measured in $e^+e^-$ collisions at 3.1 GeV. A fit to the $f^0$ production and decay angular distributions yields the values $A_1/A_0 = 0.6 \pm 0.3$ and $A_2/A_0 = 0.3\,^{+0.6}_{-1.6}$ where $A_\lambda$ are the $f^0$ helicity amplitudes. These results are in good agreement with the values predicted from a QCD two-gluon-exchange model. In addition an upper limit of $2.3 \times 10^{-4}$ is obtained for the $J/\psi \to f'^0(1514)\gamma$ decay branching ratio which implies $\Gamma(J/\psi \to f'\gamma)/\Gamma(J/\psi \to f^0\gamma) \leq 0.12 \pm 0.05$.

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Recently the $J/\psi \to f^0\gamma$ decay branching ratio has been measured by the PLUTO collaboration[1] to be $(2.0 \pm 0.3) \times 10^{-3}$. A similar result for this branching ratio of $(0.9 - 1.5) \times 10^{-3}$ has been reported by the DASP collaboration[2]. These values exclude a VDM description of the $J/\psi \to f^0\gamma$ decay mode in terms of the $J/\psi \to f^0\omega$ transition, the branching ratio of which was measured[3] to be $(4.0 \pm 1.4) \times 10^{-3}$. One notes, however, that the $J/\psi \to f^0\gamma$ rate is comparable to those reported[4] for the $J/\psi$ radiative decays into $\eta\gamma$ and $\eta'\gamma$. Hence a common description of these three $J/\psi$ radiative decays is an attractive possibility. Since the $\eta$ and $\eta'$ are pseudoscalar mesons, their production and decay distributions in the $e^+e^- \to J/\psi \to \eta(\eta')\gamma$ process are uniquely fixed. On the other hand, since the $f^0$ has a spin 2, the process

$$e^+e^- \to J/\psi \to f^0\gamma \to \pi^+\pi^-\gamma \qquad (1)$$

is described by three independent amplitudes. Thus a measurement of the production and decay angular distributions of process (1) should yield additional information on the OZI violating $J/\psi$ radiative decay transitions. A currently favoured QCD model[5] for these transitions is the one in which the photon is coupled to the charm (anticharm) quark of the $J/\psi$ particle and the final state isoscalar meson is mediated via a two-gluon-exchange mechanism. In the framework of this QCD diagram, M. Krammer[6] has recently evaluated the expected production and decay distributions of process (1). Similar distributions have also been derived by W. Gampp and H. Genz[7] using a tensor meson dominance (TMD) model.

In this letter we present our results for the $f^0$ polarization in the $J/\psi \to f^0\gamma$ decay obtained in an $e^+e^-$ collision experiment at 3.1 GeV center of mass energy. To verify the method used in the $f^0$ analysis, we have studied the production and decay properties of the process

$$e^+e^- \to J/\psi \to \rho^0\pi^0 \to \pi^+\pi^-\pi^0 \qquad (2)$$

which is described by one amplitude only and hence is completely determined.

The experiment was carried out with the magnetic detector PLUTO at the DESY electron-positron storage ring DORIS. The detector consists of a superconducting solenoid having 2 T magnetic field parallel to the beams. The useful magnetic volume of 1.4 m diameter and 1.0 m length is filled with 14 cylindrical proportional wire chambers used both for triggering and track recording. In this way a total of 0.94 x $4\pi$ str geometrical acceptance is obtained for charged particles. Two concentric layers of lead converters of radii 38 and 59 cm are incorporated in the detector having respectively 0.44 and 1.70 radiation lengths. The trigger efficiencies for the $\pi^+\pi^-\pi^0$ and $\pi^+\pi^-\gamma$ configurations of interest in this work, are 75 % and 73 % respectively. Additional details concerning the detector and its performance have been given elsewhere[8].

Out of ~84000 $J/\psi$ hadronic decay events, a final sample of 1369 two-prong events associated with one visible photon fitted the two unresolvable hypotheses $\pi^+\pi^-\pi^0$ and $\pi^+\pi^-\gamma$ with $\chi^2 \leq 20$. The selection and identification methods used have previously been published in connection with the measurement of the $J/\psi \to f^0\gamma$ decay branching ratio[1]. To remove QED and other background events we have introduced a collinearity cut of 4.4$^0$ between the two charged particles and a 16$^0$ cut between each of the charged tracks and the photon direction. In addition we used the cut $0.6 \leq M(\pi^\mp\pi^0) \leq 1.0$ GeV to remove $J/\psi \to \rho^\pm\pi^\mp$ events. The invariant mass $M(\pi^+\pi^-)$ distribution for the remaining 478 events is shown in Fig. 1. The solid line in the figure represents the best fit to the data taking two Breit-Wigner resonances for the $\rho^0$ and $f^0$ particles and a polynomial background (dashed curve).

To determine what fraction, if any, of the enhancement seen at 1.25 GeV is due to f'(1514), we reanalysed the data by fitting them to the $e^+e^- \to K^+K^-\gamma$ hypothesis. To reduce sufficiently QED events and other background and to enhance the f' over the $f^0$ events, a collinearity cut of $\geq 60^0$ and a $\chi^2 \leq 5$ cut are



imposed. The invariant mass distribution $M(K^+K^-)$ of the remaining 95 events does not show any resonance structure in the f'(1514) mass region. Assigning the 3 events seen in the range of $1.48 \leq M(K^+K^-) \leq 1.54$ GeV to the f' resonance, we infer an upper limit for the $J/\psi \to f'\gamma$ decay branching ratio of $BR(J/\psi \to f'\gamma) \leq (3.0 \pm 1.7) \times 10^{-4}$ with 90 % confidence level. Moreover, via a Monte-Carlo programme we estimate that out of the $J/\psi \to f^0\gamma$ events shown in Fig. 1, $3 \pm 1$ events fall in the 1.48 - 1.54 GeV mass range when fitted to the $K^+K^-\gamma$ final state. This then leads to an upper limit of $BR(J/\psi \to f'\gamma) \leq 2.3 \times 10^{-4}$ with 90 % confidence level. This limit, which is comparable to the one given in reference 2, assures that the f' resonance does not contribute to our $f^0$ signal.

For the study of the production and decay angular distributions of the $J/\psi \to f^0\gamma$ decay in process (1) we have taken the $f^0$ mass band to be between 1.15 and 1.40 GeV containing 62 events. The background under the $f^0$ mass band was determined from the mass fit to be ~51 %. To estimate the angular behaviour of this background we have used the neighbouring mass bands of 1.00 - 1.15 and 1.40 - 1.60 GeV each containing 26 events. We have then assumed the background under the $f^0$ resonance to be represented by the average behaviour of these two side bands. The angular distributions, $\cos\vartheta_p$, $\cos\vartheta_M$ and $\varphi_M$ of the $f^0$ mass band are shown in figures 2d-f. The production angle $\vartheta_p$ is defined as the angle between the $f^0$ meson and the positron flight directions measured in the the overall $e^+e^-$ center of mass system. The polar $\vartheta_M$ and the azimuthal $\varphi_M$ decay angles are those of the $\pi^+$ meson measured in the helicity frame of the $\pi^+\pi^-$ center of mass system. In this frame, the z-axis is defined by the flight direction of the $\pi^+\pi^-$ system. The y-axis is the normal to the $f^0$ production plane and is given by $\vec{f^0} \times \vec{e^+}$ . The x-axis is finally defined by $\vec{y} \times \vec{z}$. The $\varphi_M$ angle is measured from the x-y plane.

The $J/\psi \to f^0\gamma$ production and decay process is described by three independent $f^0$ helicity amplitudes $A_0$, $A_1$ and $A_2$. Denoting $x = A_1/A_0$ and $y = A_2/A_0$, the combined production and decay angular distribution for process (1) is proportional to[6,9]

$$W_{f^0}(\vartheta_p,\vartheta_M,\varphi_M) \propto (1+\cos^2\vartheta_p)\left[(3\cos^2\vartheta_M-1)^2+\tfrac{3}{2}y^2\sin^4\vartheta_M\right]+3x^2\sin^2\vartheta_p\sin^2 2\vartheta_M$$
$$-\sqrt{3}\,x\sin 2\vartheta_p\sin 2\vartheta_M\left[3\cos^2\vartheta_M-1-\sqrt{\tfrac{3}{2}}\,y\sin^2\vartheta_M\right]\cos\varphi_M$$
$$+\sqrt{6}\,y\sin^2\vartheta_p\sin^2\vartheta_M(3\cos^2\vartheta_M-1)\cos 2\varphi_M \qquad (3)$$

where x and y may have any value between plus and minus infinity(§). To fit expression (3) to our data, we have used a Monte-Carlo programme which simulates the details of the experimental setup and event analysis including all cuts. With this programme we have generated samples of events according to process (1). Each sample was weighted by $W_{f0}(\vartheta_p,\vartheta_M,\varphi_M)$ with different x,y values and normalised to the number of data events above background. For each pair of x,y values the three generated angular distributions, $W_{f0}(\cos\vartheta_p)$, $W_{f0}(\cos\vartheta_M)$ and $W_{f0}(\varphi_M)$ were compared with the data by means of a $\chi^2$ value. The overall $\chi^2$, summed over the three distributions, was calculated taking into account the statistical error of each bin content as well as the estimated error associated with the background subtraction. The results are presented in Fig. 3 in terms of equal $\chi^2$ value contours drawn in the x-y plane. The $\chi^2$ values assigned to the curves are measured from the minimum $\chi^2$ value of 26 (crossed point) obtained for 25 degrees of freedom. The best x,y values obtained in the fit are $x = A_1/A_0 = 0.6 \pm 0.3$ and $y = A_2/A_0 = 0.3\,^{+0.6}_{-1.6}$ corresponding to the angular distributions given by the solid lines in Figures 2d, 2e and 2f. We have repeated the fit varying the background percentage in the $f^0$ mass band in the range of 40 to 60 %. Within this range no appreciable difference from the results given in Fig. 3 is observed. However, a fit of expression (3) to the background distributions yields a rather different result, namely, a minimum $\chi^2$ of 77 at x = -1.2 and y = -0.4, for the same degrees of freedom.

(§) Note that the formula given here differs somewhat from the one given in references 6 and 9 since the z-axis is here defined by the $f^0$ and not by the photon direction.



As can be seen, the equal $\chi^2$ contours of Fig. 3 exhibit a large degree of symmetry between positive and negative x values. In fact a complete symmetry is expected for an experimental acceptance uniformly distributed over the whole kinematical allowed region for process (1). In that case the integrated angular distributions $W_{f0}(\cos\vartheta_p)$, $W_{f0}(\cos\vartheta_M)$ and $W_{f0}(\varphi_M)$ do not depend on the sign of x. A good differentiation between positive and negative x values can in principle be obtained when the fit is made over small regions in the 3-dimensional $\vartheta_p$, $\vartheta_M$, $\varphi_M$ space thus retaining the full angular correlation information. This method, however, is prohibited by our relatively small $f^0$ signal. With the fitting procedure adopted here, positive values for x are preferred, however outside the one standard deviation region negative x values are also admissible.

To check our fitting procedure we analysed by the same method the $\rho^0$ polarization in the $J/\psi \to \rho^0\pi^0$ decay given by process (2). To this end we have taken the $\rho^0$ mass band to be between 0.68 and 0.96 GeV containing 178 events. In this mass band the background amounts to ~16 %. The neighbouring $M(\pi^+\pi^-)$ bands of 0.60 - 0.68 and 0.96 - 1.04 GeV were used to estimate the background angular behaviour. The angular distributions $\cos\vartheta_p$, $\cos\vartheta_M$ and $\varphi_M$ in the mass band are shown in Fig. 2a-c. The definitions of these angles are identical to the ones used in the $J/\psi \to f^0\gamma$ analysis but replacing the $f^0$ direction by that of the $\rho^0$ meson.

The combined angular distribution $W_{\rho^0}(\vartheta_p,\vartheta_M,\varphi_M)$ for process (2) is described by only one independent helicity amplitude and is therefore uniquely fixed to be

$$W_{\rho^0}(\vartheta_p,\vartheta_M,\varphi_M) \propto (1+\cos^2\vartheta_p)\sin^2\vartheta_M + R\sin^2\vartheta_p\sin^2\vartheta_M\cos 2\varphi_M \qquad (4)$$

with R = +1. This parameter R was introduced for fitting purposes. For the best value of R we find $1.0 \pm 0.1$ with an overall $\chi^2$ value of 25.0 for 26 degrees of freedom. This result is in excellent agreement with the expected value of R = +1 for the $J^P = 1^-$ assignment to the $J/\psi$ particle. The angular distributions obtained by the fit are compared with the data by the solid lines in Figs 2a-c. We have repeated the fit adding a second free parameter representing a $\rho^0$ isotropic decay angular distribution. The best fit in this method yields again a value of R = +1 with a negligible isotropic decay component.

In conclusion, we have measured the $f^0$ polarization in the reaction $e^+e^- \to J/\psi \to f^0\gamma$ to be $x = A_1/A_0 = 0.6 \;\; 0.3$ and $y = A_2/A_0 = 0.3\,^{+0.6}_{-1.6}$ where $A_\lambda$ are the $f^0$ helicity amplitudes. Outside the one standard deviation region negative x values are also admissible. A comparison between our results and the expected values for pure E1, M2 or E3 $J/\psi \to f^0\gamma$ multipole radiative decays are made in Fig. 3. Only the M2 transition lies within one standard deviation from our best values. The values of $x = 0.76$ and $y = 0.54$ obtained from a QCD two-gluon-exchange model[6] are in very good agreement with our findings (see Fig. 3). The same is true for the nearby values of $x = 0.71$ and $y = 0.41$ derived from a tensor meson dominance (TMD) model[7]. Thus a differentiation between these two models cannot rest on the $f^0$ polarization measurement alone. Finally, combining the upper limit for the $J/\psi \to f'\gamma$ branching ratio with the rate for $J/\psi \to f^0\gamma$ measured in the same experiment[1], we infer $\Gamma(J/\psi \to f'\gamma)/\Gamma(J/\psi \to f^0\gamma) \leq 0.12 \pm 0.05$. This value is in disagreement with the value of 0.5 expected for an $SU_3$ pure singlet mixing with the $c\bar{c}$ states[10].

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Figure Captions

1. The $M(\pi^+\pi^-)$ distribution excluding events lying in the $\rho^\pm$ mass bands. The solid line represents the best fit to the data and the dashed curve is the estimated background.
2. The production $\cos\vartheta_P$ and decay $\cos\vartheta_M$ and $\varphi_M$ angular distributions for: (a), (b) and (c) $e^+e^- \to J/\psi \to \rho^0\pi^0 \to \pi^+\pi^-\pi^0$ and (d), (e) and (f) $e^+e^- \to J/\psi \to f^0\gamma \to \pi^+\pi^-\gamma$. The solid lines represent the best fit to the data.
3. Equal $\chi^2$ contours drawn in the $x = A_1/A_0$, $y = A_2/A_0$ plane obtained from the fit to the $e^+e^- \to J/\psi \to f^0\gamma \to \pi^+\pi^-\gamma$ process. The crossed point is the minimum value. The predicted QCD and TMD points are taken from references 6 and7. The expected values for pure E1, M2 and E3 multipole radiation transitions are also shown.

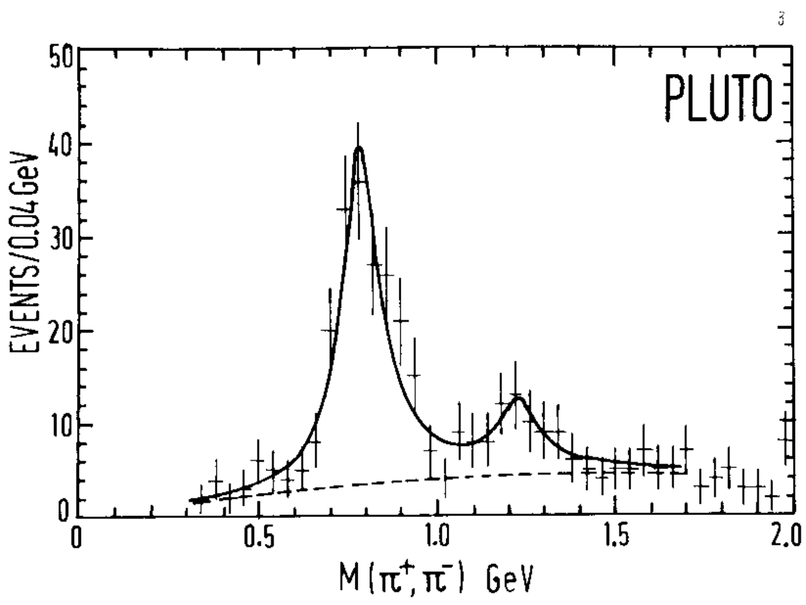
PLUTO
EVENTS/0.04 GeV
M(π⁺, π⁻) GeV

Fig. 1

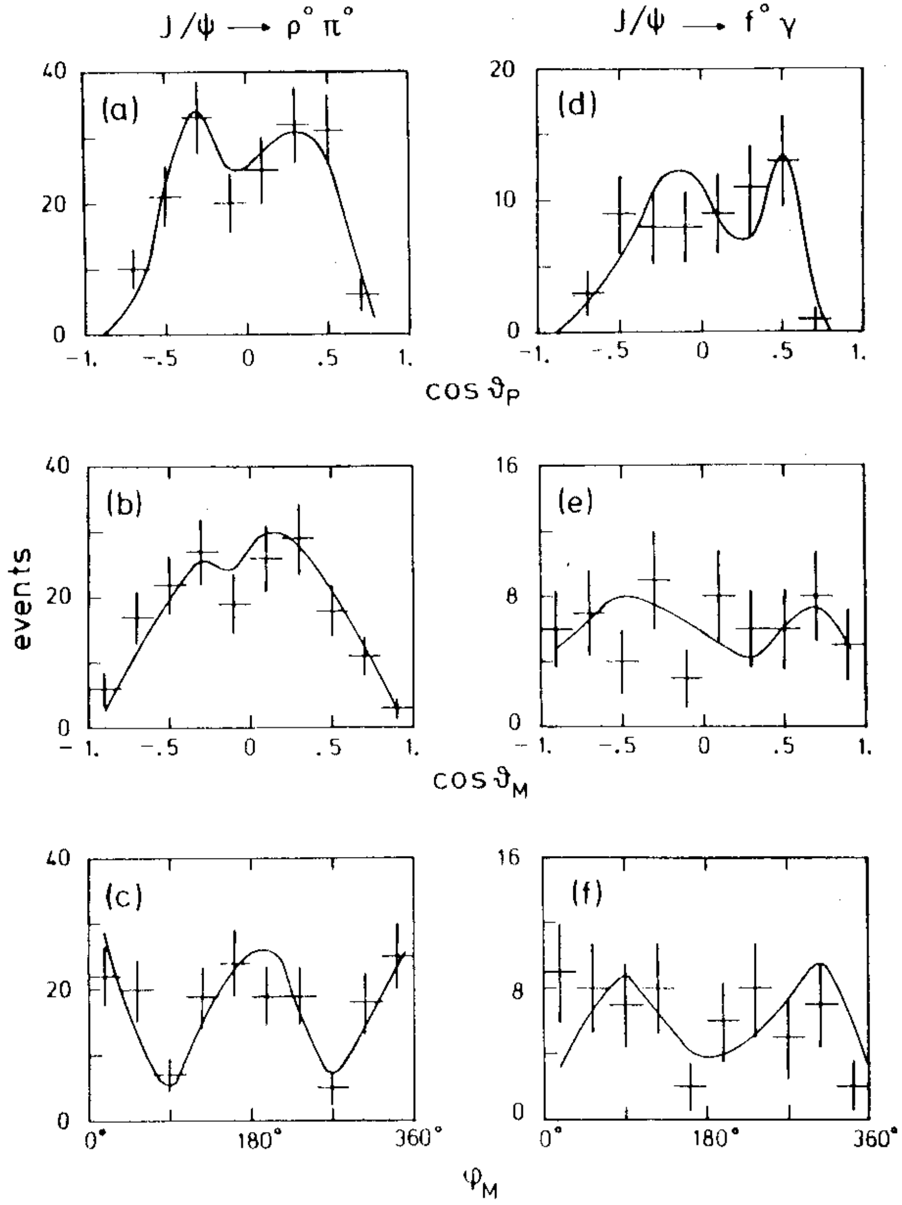
J/ψ ⟶ ρ° π°
J/ψ ⟶ f° γ
(a)
(b)
(c)
(d)
(e)
(f)
events
cos ϑ_P
cos ϑ_M
φ_M

Fig. 2

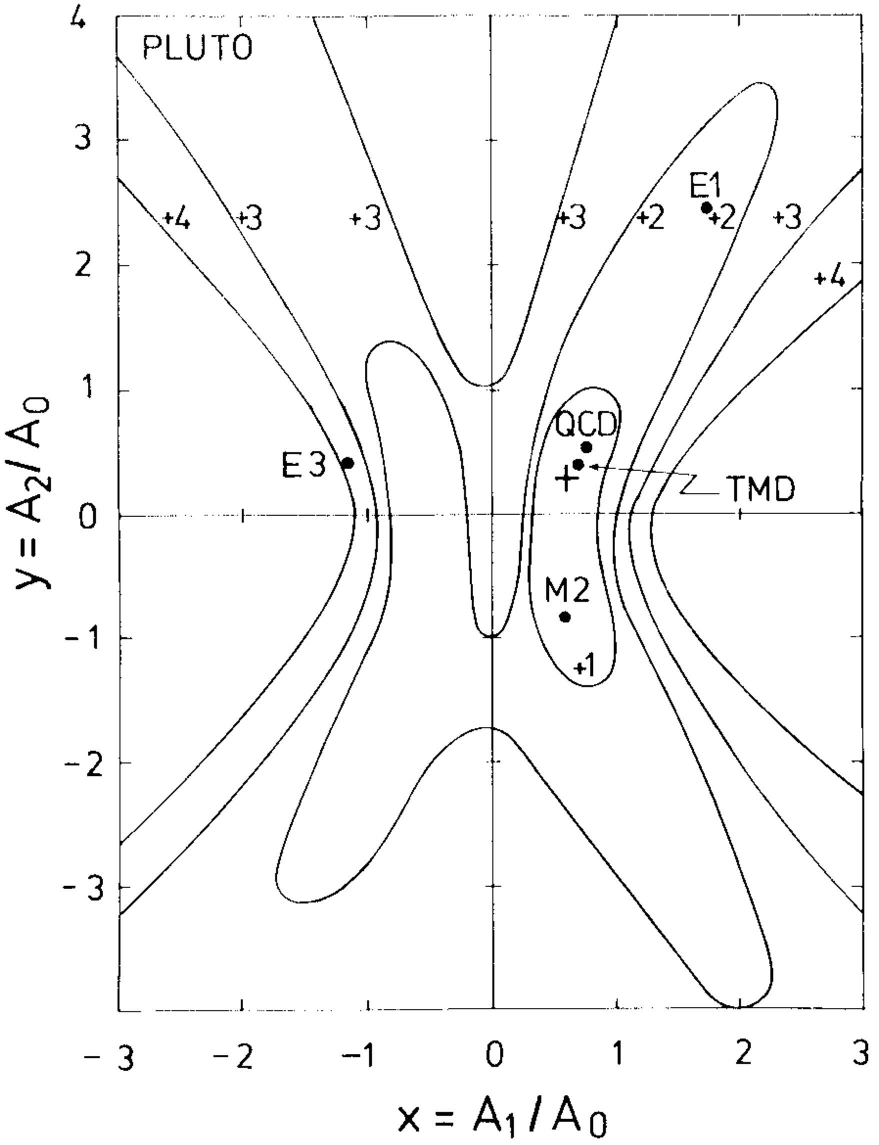


Fig. 3