DOUBLY OZI VIOLATING J/ψ DECAYS

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Two-body hadronic decays of the J/ψ are examined for evidence of doubly OZI violating (DOZI) amplitudes. Their inclusion in pseudoscalar-vector decays gives good agreement of the pseudoscalar mixing angle with new two-photon data. Using the DOZI amplitudes, we estimate the decay rate of J/ψ into gluonium and mesons using the radiative decay widths as input. We also present a qualitative analysis of decays into vector + tensor and vector + axial-vector states.

1. Introduction

Decays of the J/ψ allow a unique study of meson spectroscopy in the 1 to 2 GeV mass region. One can study quark content, gluonium, effects of $SU(3)$ breaking, electromagnetic amplitudes and spin parity for a variety of two body final states.

The prototype of such a study is the MARK III analysis of $J/\psi \to P+V$ (pseudoscalar + vector meson) final states.[1] The conclusions of that analysis that there may be substantial η', ι mixing are in conflict with the new two-photon widths for the η, η', ι.[2] As pointed out by Pinsky,[3] the principal inadequacy of the MARK III analysis is the assumption that the decays proceed via the singly disconnected (SOZI) diagram (Fig 1a) alone, while omitting the doubly disconnected (DOZI) diagrams (Fig 1b). In this paper we reconsider the $P+V$ decays, including the DOZI contribution.With the new two-photon data[4] we can input the meson quark content into the model and we can determine the DOZI amplitude. In general the SOZI amplitude implies flavor correlation between the two final state mesons while the DOZI amplitude has no such correlation and thus can be related to the radiative and glueball decays, a fact used to extract predictions for decays involving glueballs.

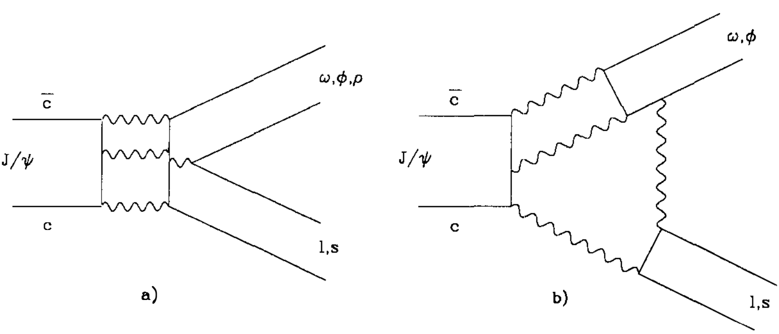

Fig. 1. Diagrams for strong J/ψ decays: a) singly disconnected (SOZI) amplitude; b) doubly disconnected (DOZI) amplitude.

There is evidence that the DOZI amplitude (Fig 1b) cannot be neglected when interfering with the dominant SOZI amplitude (Fig 1a). One process is $J/\psi \to \gamma + VV$. This decay shows a clear DOZI decay in that the $\gamma + \omega\phi$ decay is not zero,[5] but is $\sim$.3 to .5 of the allowed (SOZI) amplitude $\gamma + \omega\omega$ or $\gamma + \phi\phi$.

2. $P+V$ Final State and the Quark Content of η, η'

In the MARK III paper[1] on $J/\psi \to P+V$ only the SOZI amplitudes were included. This led to the result that the η was fully saturated with light and strange quarks while the η' wavefunction needed additional admixture ($X_{\eta'} = .36$, $Y_{\eta'} = .72$). Here we will show that assuming the quark content from the two-photon data, the inclusion of DOZI amplitudes can result in effective quark contents of the η' as measured in J/ψ decays. Writing the quark content as:

$$\eta = X_\eta \ell + Y_\eta s \ , \quad \eta' = X_{\eta'} \ell + Y_{\eta'} s \ ,$$

the two photon values imply:

$$X_\eta = .8 \quad Y_\eta = -.6 \ , \quad X_{\eta'} = .6 \ . \ Y_{\eta'} = .8 \ ,$$

where $\ell = \frac{u\bar{u} + d\bar{d}}{\sqrt{2}}$ and $s = s\bar{s}$. This corresponds to a singlet-octet mixing angle of about -19°,[4] with no need for any gluonium admixtures. As shown in Refs. 6 and 7, many observations are in good agreement with the above quark content.

In calculating the ratios of rates we take the DOZI amplitude to be r times the SOZI amplitude times a coupling factor depending on the quark flavor (any out of phase part will be small in the rate and is ignored). For simplicity we take the $SU(3)$ violation to be the same for all amplitudes (relaxed in next section) and ignore the electromagnetic amplitude which was shown in Ref. 1 to be mostly out of phase with the strong amplitude. The coupling of the DOZI amplitude to ℓ is $\sqrt{2}$ times the coupling to s. For the final states shown in Fig 1b, we get the following amplitudes relative to the SOZI amplitude :

$$\sqrt{2}r(\sqrt{2}) \ \text{ for } \omega\ell, \quad r(\sqrt{2}) \ \text{ for } \phi\ell, \quad \sqrt{2}r \ \text{ for } \omega s, \quad r \ \text{ for } \phi s \ .$$

We now use ratio's of J/ψ decay rates to estimate DOZI contributions. The ratios of relative rates are proportional to the squares of apparent wave function coefficients X^{Eff} and Y^{Eff} (which reduce to the two-photon values if $r = 0$):

$$\text{from } \frac{\omega\eta}{\rho^0\pi^0} \text{ we get: } X_\eta^{\text{Eff}} = X_\eta + \sqrt{2}r(\sqrt{2}X_\eta + Y_\eta) = .8 + .7r \quad ,$$

$$\text{from } \frac{\omega\eta'}{\rho^0\pi^0} \text{ we get: } X_{\eta'}^{\text{Eff}} = X_{\eta'} + \sqrt{2}r(\sqrt{2}X_{\eta'} + Y_{\eta'}) = .6 + 2.3r \quad ,$$

$$\text{from } \frac{\phi\eta'}{\phi\eta} \text{ we get : } \frac{Y_{\eta'}^{\text{Eff}}}{Y_\eta^{\text{Eff}}} = \frac{Y_{\eta'} + r(\sqrt{2}X_{\eta'} + Y_{\eta'})}{Y_\eta + r(\sqrt{2}X_\eta + Y_\eta)} = \frac{.8 + 1.6r}{-.6 + .5r} \quad .$$

The most striking feature of the data is the observed small value of $X_{\eta'}^{\text{Eff}}$. With $r = -0.13$ we get the effective quark content shown in Table 1 :

TABLE 1. COMPARISON $J/\psi \to P + V$

Calculated (r=-.13)	From Ref. 1
$\lvert X_\eta^{\text{Eff}}\rvert^2 = .49$	$.48 \pm .10$
$\lvert X_{\eta'}^{\text{Eff}}\rvert^2 = .09$	$.13 \pm .04$
$\frac{\lvert Y_{\eta'}^{\text{Eff}}\rvert^2}{\lvert Y_\eta^{\text{Eff}}\rvert^2} = .8$	$.76 \pm .14$

We now proceed with a full calculation of the $P+V$ rates. The parametrization of the amplitudes[1] is given in Table 2. The rates are given by $|Amp|^2 p^3$ and the $X_\eta, Y_\eta, X_{\eta'}, Y_{\eta'}$ will be calculated in several ways to check for consistency. The $SU(3)$ violation in the DOZI contribution to processes like $\phi\eta$ comes from the ϕ vertex only and is therefore assumed to be smaller than in the SOZI process.

TABLE 2. PARAMETRIZATION OF AMPLITUDES FOR $J/\psi \to P+V$

Process	Amplitude
$\rho^+\pi^-, \rho^0\pi^0, \rho^-\pi^+$	$g+e$
$K^{*+}K^-, K^{*-}K^+$	$g-h+e(2-x)$
$K^{*0}\overline{K}^0, \overline{K}^{*0}K^0$	$g-h-2e(\frac{1+x}{2})$
$\omega\eta$	$(g+e)X_\eta + \sqrt{2}rg(\sqrt{2}X_\eta + Y_\eta)$
$\omega\eta'$	$(g+e)X_{\eta'} + \sqrt{2}rg(\sqrt{2}X_{\eta'} + Y_{\eta'})$
$\phi\eta$	$(g-2h-2ex)Y_\eta + r(g-h)(\sqrt{2}X_\eta + Y_\eta)$
$\phi\eta'$	$(g-2h-2ex)Y_{\eta'} + r(g-h)(\sqrt{2}X_{\eta'} + Y_{\eta'})$
$\rho^0\eta$	$3eX_\eta$
$\rho^0\eta'$	$3eX_{\eta'}$
$\omega\pi^0$	3e
$\phi\pi^0$	0

In the table the SOZI amplitude is g, h characterizes the $SU(3)$ violation and e is the electromagnetic amplitude. The phase of e is θ_e. Here, x characterizes the $SU(3)$ violation in the electromagnetic decays and is taken to be .62.[1] All data are from MARK III,[1] except the rate for $\rho^0\eta'$, which is from DM2.[9] Common systematic errors due to normalization have been omitted in the MARK III data.

Additional input are the two-photon width $\Gamma_{\gamma\gamma}$ of π^0, η, η' [4]

$$\frac{\Gamma_{\gamma\gamma}(\eta)}{\Gamma_{\gamma\gamma}(\pi^0)} \times \left(\frac{m_\pi^0}{m_\eta}\right)^3 = \frac{25}{9}\left|X_\eta + \frac{\sqrt{2}}{5}Y_\eta\right|^2 = 1.11 \pm 0.09$$

$$\frac{\Gamma_{\gamma\gamma}(\eta')}{\Gamma_{\gamma\gamma}(\pi^0)} \times \left(\frac{m_\pi^0}{m_{\eta'}}\right)^3 = \frac{25}{9}\left|X_{\eta'} + \frac{\sqrt{2}}{5}Y_{\eta'}\right|^2 = 1.57 \pm 0.15 \quad ,$$

and the ratio of J/ψ radiative branching ratios into η and η' [10]

$$\frac{B(J/\psi \to \gamma\eta)}{B(J/\psi \to \gamma\eta')} \cdot \left(\frac{P_{\eta'}}{P_\eta}\right)^3 = \left|\frac{\sqrt{2}\,X_\eta + Y_\eta}{\sqrt{2}\,X_{\eta'} + Y'_\eta}\right|^2 = 0.166 \pm 0.025 \quad .$$

Results of the fits for $|g|$, $|h|$, $|e|$, θ_e, r and X,Y are given in Table 3 for fits using the values of Table 2 alone and for fits using also the two-photon widths and radiative decays, which independently measure X_η,Y_η, $X_{\eta'}$,$Y_{\eta'}$. We require here that both η and η' independently are saturated by light and strange quarks.

TABLE 3. P-V FIT RESULTS INCLUDING DOZI

	Input from Table 2 Alone	Input from $\Gamma_{\gamma\gamma}(\eta,\eta')$, $\frac{J/\psi\to\gamma\eta}{J/\psi\to\gamma\eta'}$ and Table 2
g	1.19 ± 0.05	1.13 ± 0.04
h	0.23 ± 0.05	0.17 ± 0.04
e	0.14 ± 0.01	0.13 ± 0.01
θ_e	1.2 ± 0.2	1.2 ± 0.2
r	-0.13 ± 0.01	-0.14 ± 0.01
X_η	0.70 ± 0.05	0.81 ± 0.01
Y_η	-0.70 ± 0.05	-0.58 ± 0.01
X'_η	0.46 ± 0.04	0.51 ± 0.02
Y'_η	0.89 ± 0.08	0.86 ± 0.04
χ^2/DF (Prob)	3.1/3 (38%)	11.1/6 (8.6%)

As one can see, the results of the fits are very stable. The value for the DOZI amplitude r is $r = -0.13 \pm 0.01$, as in the simple calculation above. The $SU(3)$ breaking term h is small, equalling 20% of g.

Setting $r = 0$ gives non-acceptable fits with typically $\chi^2/DF = 57/7$. It is quite remarkable that the fit results for X_η are identical for either the J/ψ decays or the two-photon data as input (we assume here that $X_{\eta'} = -Y_\eta$ and $Y^2 + X^2 = 1$):

$X_\eta = 0.83 \pm 0.01$ for $\Gamma_{\gamma\gamma}(\eta,\eta')$ and $B(J/\psi \to \gamma\eta)/B(J/\psi \to \gamma\eta')$ alone,

$X_\eta = 0.84 \pm 0.01$ for PV amplitudes of Table 2 alone,

$X_\eta = 0.83 \pm 0.01$ for $\Gamma_{\gamma\gamma}(\eta,\eta')$, $B(J/\psi \to \gamma\eta)/B(J/\psi \to \gamma\eta')$ and PV amplitudes of Table 2.

3. Iota Production, Assuming it to be a Glueball

The DOZI graph provides a direct way to produce glueballs with hadrons in J/ψ decay. The diagram is shown in Fig 2.

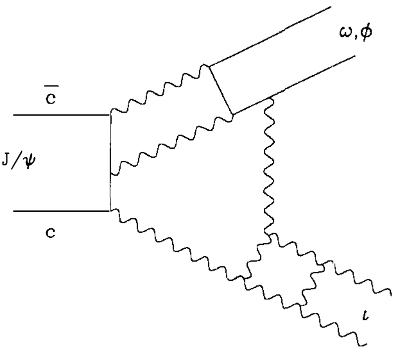

Fig. 2. Diagram for J/ψ decays into vector meson and glueball.

We get the amplitudes by comparing radiative ι, η and η' production because they are expected to occur via the two gluon intermediate state. We will now use the experimental fact that the rate for $\gamma\iota$ is equal to the sum of rates for $\gamma\eta$ and $\gamma\eta'$, and set the "DOZI"rate into gluonium equal to the total DOZI rate into quark singlets. Then one predicts the following rates in the approximation where the small electromagnetic term is ignored in the $\rho^0\pi^0$ calculation:

$$\frac{Br(J/\psi \to \omega\iota)}{Br(J/\psi \to \rho^0\pi^0)} = \left(\sqrt{6}\, r\right)^2 \left(\frac{P_\omega}{P_\rho}\right)^3 , \frac{Br(J/\psi \to \phi\iota)}{Br(J/\psi \to \rho^0\pi^0)} = \left(\frac{g-h}{g}\right)^2 \left(\sqrt{3}\, r\right)^2 \left(\frac{P_\phi}{P_\rho}\right)^3 \quad .$$

Using $r = -.13$ gives the predictions:

$$Br(J/\psi \to \omega\iota) = 1.5 \times 10^{-4} \quad , \quad Br(J/\psi \to \phi\iota) = .4 \times 10^{-4} \quad .$$

These may be compared to the MARK III 90% C.L. limit $Br(J/\psi \to \phi\iota) \leq 2.1 \times 10^{-4}$ and the ω "E" rate into $K\bar{K}\pi$ of $6.8^{+1.9}_{-1.6} \pm 1.7 \times 10^{-4}$.[11] The hadronic ι production is predicted not to be observed yet, as is the case.

4. Vector-Tensor Decays

We discuss only the decays which have DOZI contributions. Again r equals the ratio of DOZI to SOZI amplitudes. The f, f' are assumed to be ideally mixed and θ is taken to be a glueball. As in the ι case, the amplitude ratios for $\theta : f : f'$ are $\sqrt{3} : \sqrt{2} : 1$. This would give good agreement with rates for $\gamma\theta$, γf, $\gamma f'$, but glosses over the different helicity structure in the radiative decays. Normalizing to $\rho^0 A_2^0$, Table 4 gives the predictions, where the electromagnetic amplitudes are ignored. $SU(3)$ breaking is assumed to work as in the $P + V$ case, with the amplitude reduced by .8 for the production of 1 $s\bar{s}$, and .6 for 2 $s\bar{s}$.

TABLE 4. PREDICTIONS FOR $J/\psi \to V + T$

Channel	Rate Prediction	Experiment[8]	Prediction for $r = .15$
$\frac{\omega f}{\rho^0 A_2^0}$	$\lvert 1 + 2r\rvert^2 \left(\frac{P_\omega}{P_\rho}\right)$	$1.5 \pm .4$	1.69
$\frac{\phi f'}{\rho^0 A_2^0}$	$\lvert .6 + .8r\rvert^2 \left(\frac{P_\phi}{P_\rho}\right)$	$.24 \pm .06$	.35
$\frac{\phi f}{\rho^0 A_2^0}$	$\lvert .8\sqrt{2}r\rvert^2 \left(\frac{P_\phi}{P_\rho}\right)$	$.03 \pm .02$	.03
$\frac{\omega f'}{\rho^0 A_2^0}$	$\lvert .8\sqrt{2}r\rvert^2 \left(\frac{P_\omega}{P_\rho}\right)$	.045 90% C.L. Limit	.03
$\frac{\omega \theta}{\rho^0 A_2^0}$	$\lvert \sqrt{6}r\rvert^2 \left(\frac{P_\omega}{P_\rho}\right)$	$.2 \pm .06$	.12
$\frac{\phi \theta}{\rho^0 A_2^0}$	$\lvert .8\sqrt{3}r\rvert^2 \left(\frac{P_\phi}{P_\rho}\right)$	$.07 \pm .05$	.03

In the above $Br(J/\psi \to \rho^0 A_2^0)$ has been taken to be 3.3×10^{-3}, $Br(f' \to \mathrm{K\overline{K}}) = .77$, and $Br(\theta \to \mathrm{K\overline{K}}) = .67$.

Allowing a phase angle for r would reduce the first two predictions relative to the others. We see that the DOZI diagram with $r = .15$ allows a reasonable understanding of the relative sizes of all the branching ratios, which before were hard to fit into a coherent picture.[13]

Note the small ϕf signal would be hard to understand in terms of wave function mixing, since then we would expect:

$$\frac{Br(\phi f)}{Br(\phi f')} = \frac{P_f}{P_{f'}} \left(\frac{Y_f}{Y_{f'}}\right)^2 \simeq .12$$

which gives too large a strange component in the f. The model also correctly predicts that $\omega\theta$ is approximately 4 times $\phi\theta$ and the individual rates.

5. Vector-Axial Vector Decays

This is the final set of multiplets on which new data exists. The observed pattern is quite unusual and is difficult to explain without either DOZI contributions or contributions from different particles with nearly identical mass. We assume below that all signals seen in D and E mass region are the normal $q\bar{q}$ axial vectors expected around this mass.

To begin the analysis we need to infer the quark contents in these mesons. To calculate these we use the rates for γD relative to γE[12] assumed to proceed via the singlet two gluon (off-mass shell) diagram. A reasonable solution, which is meant to be indicative of what can happen, is:

$$D = \frac{2\ell - s}{\sqrt{5}} \quad \text{and} \quad E = \frac{\ell + 2s}{\sqrt{5}} \quad .$$

This gives a prediction:

$$\frac{Br(J/\psi \to \gamma D)}{Br(J/\psi \to \gamma E)} = \left[\frac{(2\sqrt{2}-1)}{\sqrt{2}+2}\right]^2 \frac{P_D}{P_E} = \frac{1}{3.5} \quad .$$

The wave functions above imply that both D and E are produced in $\pi^- p \to (\eta\pi\pi)n$ and $(K\overline{K}\pi)n$. In this case we predict:

$$\frac{\sigma(\pi^- p \to En)}{\sigma(\pi^- p \to Dn)} = \frac{1}{4} \quad .$$

Note that E production has been observed in off-shell two-photon reactions.[14] The two-photon width of the E is proportional to

$$\Gamma_{\gamma\gamma}(E) \propto \left(X_E + \frac{\sqrt{2}}{5} Y_E\right)^2 \quad .$$

With the wave function choice above this is only a factor of two smaller than the case $X_E = 1$. Also the two-photon rate for D production is predicted to be $\simeq$ rate for E production.

We now calculate the rates for $\omega E, \omega D, \phi E, \phi D$ including a DOZI contribution. We again ignore the electromagnetic term and make the same assumption about $SU(3)$ breaking as for the vector-tensor case. Rates will be relative, up to an overall factor. The results are given in Table 5.

TABLE 5. V + A PREDICTIONS

Channel	Relative Rates	Relative Rates, $r = -.44$
ωD	$\lvert 2+\sqrt{2}r(2\sqrt{2}-1)\rvert^2$	.77
ωE	$\lvert 1+\sqrt{2}r(\sqrt{2}+2)\rvert^2 \frac{P_E}{P_D}$	1.14
ϕD	$\lvert -.6+.8r(2\sqrt{2}-1)\rvert^2 \frac{P_\phi}{P_\omega}$	1.3
ϕE	$\lvert 1.2+.8r(\sqrt{2}+2)\rvert^2 \frac{P_\phi}{P_\omega}$	0

The data indicate that ϕE is small [8,11]. We will use this to determine r. Setting the ϕE rate = 0 implies $r = -.44$. The relative rates for ωD and ωE come out quite close to what is seen. The absolute ϕD rate is too large, while ϕE is absent. The absolute ϕD rate depends on the assumed amount of $SU(3)$ breaking which, unfortunately, we cannot yet measure. Another factor of two in the $SU(3)$ breaking is needed in the ϕD amplitude to get about the correct rate.

Note, in the case above the pattern has been completely scrambled from the naive SOZI expectations which would be:

$\omega D/\omega E = 4$ and $\phi D/\phi E = \frac{1}{4}$.

6. Conclusions

We have looked at a range of data on J/ψ decays in terms of a simple decay model incorporating both SU(3) violation and the effect of doubly disconnected (DOZI) diagrams. In the case of the pseudoscalar mesons, the model gives good agreement with the quark wave functions determined from two-photon decays. We have extended the model to predict the rate of hadronic production of the glueball ι, which comes out smaller than present upper limits.

In the case of vector plus tensor or vector plus axial-vector decays, the model predicts a pattern of rates which is in general agreement with the data. The use of radiative J/ψ decays, as well as two-photon widths, should serve to determine the quark content of the axial-vectors. Initial results, surprisingly, indicate that this multiplet is not ideally mixed. Better results in the case of the tensor mesons should serve to check more quantitatively our model assumptions and the assignment of the θ as a gluonium state.

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