# $\psi' \to \psi\eta$: SU(3)-allowed or SU(3)-symmetry-breaking?*

M. Machacek† and Y. Tomozawa
*Randall Laboratory of Physics, University of Michigan, Ann Arbor, Michigan 48104*
(Received 6 October 1975; revised manuscript received 20 October 1975)

We investigate the SU(3) nature of the $\psi' \to \psi\eta$ decay by comparing its effective coupling constant with that for the SU(3)-allowed $\omega \to \rho\pi$ coupling using the $\omega \to \pi\gamma$ decay width and $\rho$ dominance of the photon. The result is completely consistent with an SU(3)-symmetry-breaking interpretation of the $\psi' \to \psi\eta$ decay.

## I. INTRODUCTION

Since the discovery of the narrow resonances[1] $J(\psi)(3.095)$ and $\psi'(3.684)$ many models have been constructed which use the idea that these resonances are quark-antiquark bound states of some new heavy quarks. The standard model,[2] the charmed 4-quark model, interprets the $\psi$ and $\psi'$ as SU(3) singlet $c\bar{c}$ bound states, where $c$ is the new heavy charmed quark and the $\psi'$ resonance is a radial excitation of the $\psi$. Most other 6-quark models keep this radial excitation interpretation for $\psi'$ or claim that although some of the new particles are nonsinglet under a new SU(3), $SU(3)_H$, they all remain singlets under the SU(3) of ordinary hadrons.[3] The complete classification symmetry for hadrons then becomes the larger $SU(3)\times SU(3)_H$ group. If, as these models require, $\psi'$ and $\psi$ are SU(3) singlets, then the observed decay $\psi' \to \psi\eta$ is forbidden in the limit of exact SU(3) since

$$\underline{1} \not\subset \underline{1} \otimes \underline{8} \,. \tag{1}$$

For these models to be correct, the $\psi' \to \psi\eta$ decay should be of the order of a typical SU(3)-symmetry-breaking effect. If $\psi'$, $\psi$, or both have, however, SU(3) octet components, then the $\psi' \to \psi\eta$ is an SU(3)-allowed process.[4] Thus, the question of whether the rate for the $\psi' \to \psi\eta$ decay is consistent with an SU(3)-allowed or an SU(3)-symmetry-breaking effect is an important constraint on model building. In this paper we investigate this question by comparing the effective coupling constants for the process $\psi' \to \psi\eta$ with the SU(3)-allowed process $\omega \to \rho\pi$ using the $\omega \to \pi\gamma$ decay width and $\rho$ dominance of the photon. The Iizuka-Okubo-Zweig (IOZ) suppression factor[5] for the $\psi' \to \psi\eta$ decay is taken from the comparison of $\psi' \to \psi\pi\pi$ with $\rho'(1.6) \to \rho\pi\pi$. In Sec. II we state the theoretical preliminaries to the calculation. In Sec. III the numerical results are presented and the experimental ambiguities in the calculation are carefully discussed.

## II. THEORETICAL PRELIMINARIES

The decay of any vector meson $V'$ into another vector meson $V$ and a pseudoscalar meson $\varphi$, such as the $\psi' \to \psi\eta$, can be described by an effective interaction Lagrangian of the form

$$\mathcal{L}_{\rm int} = G\varphi\,\epsilon_{\mu\nu\lambda\rho}\partial_\mu V_\nu\,\partial_\lambda V'_\rho \,, \tag{2}$$

where $G$ is an effective coupling constant with dimensions of $[\text{mass}]^{-1}$. Other possible forms for the interaction, such as

$$G\epsilon_{\mu\nu\lambda\rho}\partial_\mu V_\nu\,\partial_\lambda\varphi\, V'_\rho$$

or

$$G\epsilon_{\mu\nu\lambda\rho}\partial_\mu V'_\nu\,\partial_\lambda\varphi\, V_\rho \,,$$

are simply related to expression (2) by a total divergence and so are equivalent. Using expression (2) the partial width for such a decay is

$$\Gamma_{V'\to V\varphi} = \frac{G^2|p_V|^3}{12\pi}, \tag{3}$$

where $|p_V|$ is the available center-of-mass momentum to each of the decay products in the $V' \to V\varphi$ decay.

The vector-dominance calculation[6] of the process $V' \to \varphi\gamma$ where the photon couples to $V'$ through a vector meson $V$, such as the $\rho$, is the similar to that for $V' \to V\varphi$. In this case the additional effective interaction Lagrangian for the coupling of $V$ to the photon is

$$\mathcal{L}_{\rm int} = \frac{eM_V^2}{f_V} V_\sigma A_\sigma \,, \tag{4}$$

where $A_\sigma$ is the photon field, $eM_V^2/f_V$ the coupling of the photon to the vector meson $V$, $M_V$ the mass of the vector meson, and $f_V$ its strong interaction coupling constant. Using expressions (2) and (4), the partial width for the decay $V' \to \varphi\gamma$ is

$$\Gamma(V' \to \varphi\gamma) = \frac{G^2 e^2 |p_\gamma|^3}{12\pi f_V{}^2} \quad , \tag{5}$$

where $|p_\gamma|$ is the available center-of-mass momentum to the photon. Note that Eq. (5) differs from Eq. (3) solely by the replacement

$$G^2 \to \frac{G^2 e^2}{f_V{}^2} \quad .$$

The IOZ suppression factor for the $\psi' \to \psi\eta$ decay is assumed to be the same as that for $\psi' \to \psi\pi\pi$.[7] This suppression factor is calculated by comparing the coupling constant for $\psi' \to \psi\pi\pi$ with that of $\rho'(1.6) \to \rho\pi\pi$ using the effective interaction Lagrangian[8]

$$\mathcal{L}_{\text{int}} = F V'_\mu V_\mu \partial_\nu \varphi \partial_\nu \varphi \ , \tag{6}$$

where $V'$, $V$ are the vector-meson fields, $\varphi$ is the pion field, and $F$ is the effective coupling constant with dimension $[\text{mass}]^{-2}$. The details of this calculation are given in the Appendix. The above form for the effective interaction Lagrangian of $V' \to V\varphi\varphi$ is chosen to reproduce the peaking at high dipion masses observed in the $\psi' \to \psi\pi\pi$ dipion mass spectrum. We assume that the same effective interaction dominates the $\rho' \to \rho\pi\pi$ decay, although the dipion mass spectrum for this latter decay is not known.

In order to compare the coupling strengths of various processes, we have to define dimensionless coupling constants by introducing appropriate mass parameters into Eqs. (2) and (6). With no *a priori* reason to choose any particular mass parameter, we will consider the following two cases:

I. A universal mass $\mu$ is used for the same type of interaction, i.e., in Eq. (2) $G(\psi' \to \psi\eta)$ and $G(\omega \to \rho\pi)$ are normalized by the same mass parameter and similarly for $F(\psi' \to \psi\pi\pi)$ and $F(\rho' \to \rho\pi\pi)$ in Eq. (6).

II. A mass characteristic of the decay is used, say the mass of the decaying particle.

It will be shown in Sec. III that these two cases lead to distinctively different IOZ suppression factors for the process $\psi' \to \psi\eta$ decay.

Case I. In terms of a dimensionless coupling constant $f$, where

$$f = F\mu^2 \tag{7}$$

and $\mu$ is some universal mass for all decays such as the pion mass, the ratio of coupling constants is

$$\frac{f(\rho' \to \rho\pi\pi)}{f(\psi' \to \psi\pi\pi)} = \left[\frac{\Gamma(\rho' \to \rho\pi\pi) M_{\rho'}{}^3 I_{\psi'}}{\Gamma(\psi' \to \psi\pi\pi) M_{\psi'}{}^3 I_{\rho'}}\right]^{1/2} . \tag{8}$$

$\Gamma(V' \to V\pi\pi)$ is the partial width of the decay $V' \to V\pi\pi$, $M_{V'}$ is the mass of the decaying particle, and $I_{V'}$ is the value of a dimensionless integral defined in the Appendix.

Similarly by defining a dimensionless coupling constant $g$ for the decay $V' \to V\varphi$ as

$$g = G_\mu \ , \tag{9}$$

where $\mu$ is again a universal mass, and using Eq. (3) and (5) the ratio of the coupling constants $g(\psi' \to \psi\eta)$ and $g(\omega \to \rho\pi)$ from $\omega \to \pi\gamma$ decay is

$$\frac{g(\psi' \to \psi\eta)}{g(\omega \to \rho\pi)} = \left(\frac{\Gamma(\psi' \to \psi\eta) 4\pi\alpha |p_\gamma|^3}{\Gamma(\omega \to \pi\gamma) f_\rho{}^2 |p_\psi|^3}\right)^{1/2} , \tag{10}$$

where $\alpha \simeq \frac{1}{137}$ is the fine-structure constant. Using expression (8) to correct for the expected IOZ suppression of $\psi' \to \psi\eta$, we find that the corrected ratio of effective coupling constants is

$$\left(\frac{g(\psi' \to \psi\eta)}{g(\omega \to \rho\pi)}\right)_{\text{corrected}} = \left(\frac{\Gamma(\psi' \to \psi\eta) 4\pi\alpha |p_\gamma|^3 I_{\psi'} M_{\rho'}^3 \Gamma(\rho' \to \rho\pi\pi)}{\Gamma(\omega \to \pi\gamma) f_\rho{}^2 |p_\psi|^3 I_{\rho'} M_{\psi'}^3 \Gamma(\psi' \to \psi\pi\pi)}\right)^{1/2} . \tag{11}$$

Case II. The alternative approach is to normalize the coupling constants $G$ and $F$ by some mass characteristic of the decay, say $M_{V'}$, rather than a universal mass. In this case Eq. (8) is modified by a factor $(M_{\rho'}/M_{\psi'})^2$, Eq. (10) by $M_{\psi'}/M_\omega$, and Eq. (11) by $M_{\rho'}{}^2/M_{\psi'}M_\omega$.

## III. RESULTS

The relevant data for the calculation of the $\psi' \to \psi\eta$ and $\psi' \to \psi\pi\pi$ decay modes are well known from recent experiments at SLAC. The current experimental parameters[9] describing these decays are

$$M_{\psi'} = 3.684\ \text{GeV},\ M_\psi = 3.095\ \text{GeV},$$

$$M_\eta = 0.549\ \text{GeV},\ |p_\psi| = 0.196\ \text{GeV},$$

$$\Gamma(\psi' \to \text{all}) = 225 \pm 56\ \text{keV}, \quad \frac{\Gamma(\psi' \to \psi\eta)}{\Gamma(\psi' \to \text{all})} = (4 \pm 2)\%$$

for $\psi' \to \psi\eta$ and

$$\frac{\Gamma(\psi' \to \psi\pi^+\pi^-)}{\Gamma(\psi' \to \text{all})} = (32 \pm 4)\%, \quad I_{\psi'} = 546$$

for $\psi' \to \psi\pi\pi$ decay. We use throughout the values[10] 0.1396 GeV and 0.0195 GeV$^2$ for the pion mass $\mu$ and mass squared $\mu^2$.

Similarly the data on $\omega \to \pi\gamma$ decay are well known[10] with

$$M_\omega = 0.7827 \text{ GeV}, \quad |p_\gamma| = 0.380 \text{ GeV},$$

$$\Gamma(\omega \to \text{all}) = 10.0 \pm 0.4 \text{ MeV}, \quad \frac{\Gamma(\omega \to \pi^0\gamma)}{\Gamma(\omega \to \text{all})} = (8.7 \pm 0.5)\% .$$

The determination[11] of the strong interaction coupling constant $f_\rho$ is not so clear with the values for $f_\rho^2/4\pi$ ranging from 2.1 to 2.8. We choose as an average value

$$\frac{f_\rho^2}{4\pi} = 2.4$$

for this calculation. Using the above data, Eq. (10), and the normalization of the coupling constants by a universal mass, i.e., Case I, the IOZ-uncorrected value for the ratio of $\psi' \to \psi\eta$ to $\omega \to \rho\pi$ coupling constants is

$$\frac{g(\psi' \to \psi\eta)}{g(\omega \to \rho\pi)} = 0.0151 . \tag{12}$$

If we had used instead the perhaps better value[11]

$$\frac{f_\rho^2}{4\pi} = 2.7 \pm 0.2 ,$$

determined by using $\rho$ dominance from the ratio $\Gamma(\omega \to \pi\gamma)/\Gamma(\omega \to 3\pi)$, this would have decreased the value in expression (12) by 6%.

The data on $\rho' \to \rho\pi\pi$ decay needed for the calculation of the expected IOZ suppression are somewhat ambiguous. In the most recent experiment, Conversi *et al.*[12] obtained a new mass value

$$M_{\rho'} = 1.550 \pm 0.06 \text{ GeV} \quad \text{(Case a)}$$

with a width

$$\Gamma(\rho' \to \text{all}) = 360 \pm 100 \text{ MeV} .$$

This gives a value for the integral $I_{\rho'}$ given in the Appendix,

$$I_{\rho'(1.55)} = 1801 .$$

Since the tabulated value for the $\rho'$ mass

$$M_{\rho'} = 1.600 \text{ GeV} \quad \text{(Case b)}$$

gives a substantially different value for this integral, i.e.,

$$I_{\rho'(1.6)} = 2961 ,$$

we shall consider both cases. We take $M_\rho = 0.770$ GeV. The greatest difficulty lies in the fact that the branching ratio $\Gamma(\rho' \to \rho\pi\pi)/\Gamma(\rho' \to \text{all})$ is essentially unknown. All that is known[10] is that the process $\rho' \to \rho\pi\pi$ is dominant with a relative branching ratio

$$\frac{\Gamma(\rho' \to \rho\pi\pi)}{\Gamma(\rho' \to \pi^+\pi^-\pi^+\pi^-)} \approx (80 - 100)\% .$$

For the sake of clarity we assume all other modes are small and that $\Gamma(\rho' \to \rho\pi\pi)/\Gamma(\rho' \to \text{all}) \approx 100\%$. This gives a partial width for $\Gamma(\rho' \to \rho\pi^+\pi^-) = 240$ MeV. Using the above data in expression (8) and again a universal mass normalization of the coupling constant (Case I) we obtain the IOZ factors

$$\frac{f(\rho' \to \rho\pi^+\pi^-)}{f(\psi' \to \psi\pi^+\pi^-)} = 8.68 \text{ for case (a)} \tag{13}$$

and

$$\frac{f(\rho' \to \rho\pi^+\pi^-)}{f(\psi' \to \psi\pi^+\pi^-)} = 7.10 \text{ for case (b)} . \tag{14}$$

Thus within the context of Case I, the decay $\psi' \to \psi\pi\pi$ is IOZ suppressed. This is consistent with the attitude that all disconnected quark diagrams should have such a suppression. Combining expression (12) with expressions (13) and (14) according to Eq. (11) gives the IOZ-corrected value for the ratio of the effective coupling constants. These are

$$\left[\frac{g(\psi' \to \psi\eta)}{g(\omega \to \rho\pi)}\right]_{\text{corrected}} = \begin{cases} 0.131, & \text{Case Ia} \\ 0.108, & \text{Case Ib.} \end{cases} \tag{15}$$

Using the alternative approach of Case II, i.e., normalizing the coupling constant by some mass characteristic of the decay, say $M_{V'}$, instead of a universal mass, the uncorrected coupling constant given in (12) is now 0.0713. The IOZ factors given in (13) and (14) become 1.537 for Case (a) and 1.339 for Case (b), respectively. Notice that this approach leads to little if any IOZ suppression of the decay $\psi' \to \psi\pi\pi$. This violates the attitude that disconnected quark diagrams should be suppressed, but may be consistent with a quark-gluon picture of the IOZ suppression. If the IOZ suppression is due to the strong interactions becoming asymptotically free, i.e., the gluon coupling constant becoming small, at high momentum transfer, one may argue that since the momentum transfer to the gluons in the process $\psi' \to \psi\pi\pi$ is small (i.e., ~0.5 GeV), the gluon coupling constant is now large[7] (> 0.5) and thus little IOZ suppression is expected. The IOZ-corrected value for the ratio of effective coupling constants, analogous to (15), is

$$\left[\frac{g(\psi' \to \psi\eta)}{g(\omega \to \rho\pi)}\right]_{\text{corrected}} = \begin{cases} 0.110, & \text{Case IIa} \\ 0.095, & \text{Case IIb}\,. \end{cases} \quad (16)$$

If SU(3) symmetry breaking is typically (10–20)% in amplitude as indicated by the analysis of the $K^+ \to \pi^+\pi^0$ and $K^0 \to 2\pi^0$ decays,[13] then all of the ratios given in (15) and (16) are completely consistent with $\psi' \to \psi\eta$ interpreted as an SU(3)-symmetry-breaking effect.

A cleaner test of the SU(3) nature of the $\psi' \to \psi\eta$ decay would be to compare that decay directly with the SU(3)-allowed decay of the radial excitation of an ordinary vector meson, say the $\omega$. The uncorrected ratio of the effective coupling constants for $\psi' \to \psi\eta$ to $\omega' \to \rho\pi$, for example, could be determined directly using Eq. (3) without the additional assumption of vector-meson dominance. The expected radial excitation $\omega'$ of the $\omega$ should lie close in mass to the radial excitation $\rho'(1.6)$ of the $\rho$ meson due to the $\rho$-$\omega$ degeneracy. One candidate[10] for such a particle, the $\omega'(1.678)$, has been found. A recent spin-parity determination[14] of the resonance, however, indicates that it may be a $3^-$ rather than the desired $1^-$ state. The $1^-$ state should be most easily found in the $3\pi$ and $5\pi$ final states of $e^+e^-$ annihilation at a mass ~1.6 GeV. We expect the width of the $1^-$ state to be larger than the 167 MeV width of the observed $3^-$ state due to its lower angular momentum. We do not, however, expect it to be much broader than ~400 MeV, the width of the $\rho'(1.6)$. Using Eqs. (3) and (8) under the assumption of Case I, i.e., a universal mass normalization of the coupling constants, the IOZ-corrected ratio of the effective coupling constants is

$$\left[\frac{g(\psi' \to \psi\eta)}{g(\omega' \to \rho\pi)}\right]_{\text{corrected}} = \left[\frac{|p_\rho|^3\Gamma(\psi' \to \psi\eta)I_{\psi'}M_{\rho'}{}^3\Gamma(\rho' \to \rho\pi\pi)}{|p_\psi|^3\Gamma(\omega' \to \rho\pi)M_{\psi'}{}^3 I_{\rho'}\Gamma(\psi' \to \psi\pi\pi)}\right]^{1/2}. \quad (17)$$

For Case II, where the mass of the decaying particle is used to normalize the effective coupling constants, Eq. (17) is modified by the factor $M_{\rho'}{}^2/M_{\psi'}M_{\omega'}$. We assume that the partial width $\Gamma(\omega' \to \rho\pi) \sim 200$ MeV and the mass $M_{\omega'} \sim 1.6$ GeV. Then the ratio of the IOZ-corrected coupling constants is in each case

$$\left[\frac{g(\psi' \to \psi\eta)}{g(\omega' \to \rho\pi)}\right]_{\text{corrected}} = \begin{cases} 0.316, & \text{Case Ia} \\ 0.258, & \text{Case Ib} \\ 0.137, & \text{Case IIa} \\ 0.112, & \text{Case IIb} \end{cases} \quad (18)$$

The values in (18) are somewhat higher, but in rough agreement with those from the vector-dominance calculation. They serve only as an illustration of what one may expect from the decay of the $1^-$ $\omega'$ state.

It is obvious that to clarify all the above calculations, one needs more precise experimental information on the existence and decays of the ordinary hadrons, in particular the $\rho'$ (1.6) and the $1^-$ radial excitation of the $\omega(0.783)$. The dipion mass spectrum for the decay $\rho' \to \rho\pi\pi$ is needed to verify that expression (6) is the correct effective interaction Lagrangian for this process. A good determination of the $\rho' \to \rho\pi\pi$ branching ratio is essential to these calculations. A firm theoretical understanding of the IOZ rule is also necessary in order to establish whether the process $\psi' \to \psi\pi\pi$ and thus $\psi' \to \psi\eta$ should be suppressed, and thus clarify which mass normalization of the effective coupling constants is most appropriate.

In conclusion, despite the theoretical and experimental ambiguities, the present calculation indicates that the decay $\psi' \to \psi\eta$ is completely consistent with an SU(3)-symmetry-breaking effect.

## ACKNOWLEDGMENTS

The authors are indebted to F. Uchiyama and D. M. Chew for helping us to find recent experimental data on the $\rho'$ and $\omega'$ resonances and to G. L. Kane for helpful comments. One of us (M.M.) would like to acknowledge the hospitality of the Aspen Center for Physics where part of this work was undertaken.

## APPENDIX: CALCULATION OF IIZUKA-OKUBO-ZWEIG SUPPRESSION FACTOR

The Iizuka-Okubo-Zweig suppression factor for the $\psi' \to \psi\eta$ is assumed to be the same as that for $\psi' \to \psi\pi\pi$. This factor is calculated phenomenologically by comparing the $\psi' \to \psi\pi\pi$ to that of $\rho' \to \rho\pi\pi$. For these decays of the $V' \to V\pi\pi$ type, the effective interaction Lagrangian is

$$\mathcal{L}_{\text{int}} = F V'_\mu V_\mu \partial_\nu \varphi \partial_\nu \varphi\,, \quad (A1)$$

where $V'$, $V$ are the vector mesons, $\varphi$ is the pion field, and $F$ is an effective coupling constant. By using the dimensionless coupling constant

$f = F\mu^2$

defined in Sec. II where $\mu$ is in this case the pion mass, we obtain the expression for the partial width

$$\Gamma(V' \to V\pi\pi) = \frac{f_{V'}^2}{48 M_{V'}^3 (2\pi)^3 \mu^4} \int_{2\mu}^{M_{V'}-M_V} d\sigma (\sigma^2 - 4\mu^2)^{1/2} \{[(M_{V'}+M_V)^2 - \sigma^2][(M_{V'}-M_V)^2-\sigma^2]\}^{1/2} \times \left[2 + \left(\frac{M_{V'}^2 + M_V^2 - \sigma^2}{2M_{V'}M_V}\right)^2\right] \frac{(\sigma^2 - 2\mu^2)^2}{4} , \tag{A2}$$

where $M_{V'}$, $M_V$, $\sigma$ are the masses of $V'$, $V$, and the dipion system, respectively. This partial width is then expressed in terms of the dimensionless integral $I_{V'}$ as

$$\Gamma(V' \to V\pi\pi) = f_{V'}^2 \mu^4 I_{V'} / 6\pi^3 M_{V'}^3 , \tag{A3}$$

where

$$I_{V'} = \int_0^1 dy\, E\{[(Ey+1)^2 - 1][A^2 - (Ey+1)^2][B^2 - (Ey+1)^2]\}^{1/2} \left\{2 + \left[\frac{C - (Ey+1)^2}{D}\right]\right\}^2 [(Ey+1)^2 - 0.5]^2 \tag{A4}$$

and

$$A = \frac{M_{V'} - M_V}{2\mu}, \quad D = \frac{2M_{V'}M_V}{4\mu^2}, \quad B = \frac{M_{V'} + M_V}{2\mu}, \quad E = A - 1, \quad C = \frac{M_{V'}^2 + M_V^2}{4\mu^2}, \quad Y = \frac{\sigma - 2\mu}{2\mu E} . \tag{A5}$$

The integral $I_{V'}$ is integrated numerically. The values of this integral for the relevant decays are

$$I_{\psi'} = 546$$

$$I_{\rho'(1.55)} = 1801 , \tag{A6}$$

$$I_{\rho'(1.6)} = 2961 ,$$

where the integral $I_{\rho'}$ has been calculated using the most recent mass value $M_{\rho'} = 1.550 \pm 0.06$ GeV and the standard tabulated value $M_{\rho'} = 1.6 \pm 0.1$ GeV.

---

*Work supported in part by the Energy Research and Development Administration.

†Junior Fellow, Michigan Society of Fellows.

[1]J. J. Aubert *et al.*, Phys. Rev. Lett. 33, 1404 (1974); J.-E. Augustin *et al.*, *ibid.* 33, 1406 (1974); G. S. Abrams *et al.*, *ibid.* 33, 1453 (1974).

[2]S. L. Glashow, J. Iliopoulos, and L. Maiani, Phys. Rev. D 2, 1285 (1970); T. Appelquist and H. D. Politzer, Phys. Rev. Lett. 34, 43 (1975); A. De Rújula and S. L. Glashow, *ibid.*, 34, 46 (1975).

[3]R. M. Barnett, Phys. Rev. Lett. 34, 41 (1975); Phys. Rev. D 11, 3246 (1975); H. Harari, Phys. Lett. 57B, 265 (1975); H. Fritzsch and P. Minkowski, Report No. CALT-68-503, 1975 (unpublished).

[4]M. Machacek and Y. Tomozawa, this issue, Phys. Rev. D 13, 1462 (1976).

[5]S. Okubo, Phys. Lett. 5, 165 (1963); G. Zweig, CERN Report No. TH-401, 1964 (unpublished); CERN Report No. TH-402, 1964 (unpublished); G. Iizuka, Prog. Theor. Phys. Suppl. 37–38, 21 (1966).

[6]M. Gell-Mann, D. Sharp, and W. Wagner, Phys. Rev. Lett. 8, 261 (1962).

[7]Although the actual mechanism of IOZ suppression is not well understood, within the context of the quark-gluon theory of strong interactions where short-range interactions occur only through gluon exchange and SU(3) symmetry breaking is solely the result of quark mass differences [see, for example, A. De Rújula *et al.*, Phys. Rev. D 12, 147 (1975)], it is reasonable to assume that the IOZ rule acts in the same way for an SU(3)-symmetry-breaking process as for an SU(3)-allowed process. Also since the dipion mass spectrum for $\psi' \to \psi\pi\pi$ peaks near the $\eta$ mass, the momentum transfer to the gluon system should be nearly equal for the $\psi' \to \psi\pi\pi$ and $\psi' \to \psi\eta$ processes. Thus, the gluon coupling constants for those gluons involved in the creation of the dipion and $\eta$ systems will be of comparable strengths. Therefore, the IOZ suppression factors for these two processes should be the same.

[8]L. S. Brown and R. N. Cahn, Phys. Rev. Lett. 35, 1 (1975).

[9]SLAC data presented at the International Symposium on Lepton and Photon Interactions, 1975 (unpublished).

[10]Particle Data Group, Phys. Lett. 50B, 1 (1974).

[11]J. J. Sakurai, Phys. Rev. Lett. 17, 1021 (1966).

[12]M. Conversi *et al.*, Phys. Lett. 52B, 493 (1974).

[13]N. Cabibbo, Phys. Rev. Lett. 12, 62 (1964); M. Gell-Mann, *ibid.* 12, 155 (1964); S. Okubo, R. E. Marshak, and V. S. Mathur, *ibid.* 407 (1967).

[14]F. Wagner, M. Tabak, and D. M. Chew, Phys. Lett. 58B, 201 (1975); M. Tabak, Ph.D. thesis, LBL-3397 Report No. LBL-3397, 1974 (unpublished).