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Zweig's Rule Violation, SU(3) Character of the Decay of the New Particles, and Pole Dominance Picture*

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ABSTRACT

The decays $\psi' \to \psi\pi\pi$ and $\psi \to \omega\epsilon$ are studied in the framework of Zweig Rule violation via SU(4) pole dominance. The SU(3) character of the decay of the ψ is discussed in the same model. Using results of the purely hadronic decays, the cascade transition rates $\psi' \to \epsilon_c + \gamma$ and $\epsilon_c \to \psi + \gamma$ are calculated and compared to recent experimental data.

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I. Introduction

If the new mesons (ψ, ψ', ...) are bound states of new quark-antiquark pairs, with decays into ordinary hadrons suppressed by Zweig's Rule[1] [in analogy to $\varphi \to 3\pi$ suppression] then a deeper understanding of that empirical rule--or at least a model in which it can be formulated and discussed--would be of great help in sorting out the increasingly detailed data on ψ and ψ' branching ratios.

Asymptotic freedom arguments qualitatively support Zweig's Rule,[2] and may eventually provide a fundamental and quantitative explanation of its violation, but at this time seem unable to make sharp prediction. The classical approach through the first order mass matrix [in which departures of $\psi(\bar{c}c)$ and $\varphi(\bar{\lambda}\lambda)$ wave functions from ideal mixing are calculable in terms of departures of the $J^P = 1^-$ meson masses from the ideal mixing mass formula] also fails to make unambiguous predictions[3] because the admixture of ordinary quarks in the ψ depends sensitively on the $\rho^o - \omega$ mass difference, requiring a detailed theory for extracting the ρ-pole position from the p-wave $\pi\pi$ background, as well as quantitative understanding of electromagnetic mass differences.

The deceptively simple picture of Freund and Nambu,[4] however, does make a number of unambiguous predictions concerning the "forbidden" decays, and succeeds in tying together several different processes, while providing a useful way of looking at the data. Some of the successes of the model have been previously reported[5] [they are (i) $\Gamma_{\psi \to \bar{p}p}/\Gamma_{\psi \to \rho\pi}$ and $\Gamma_{\psi \to \bar{\Lambda}\Lambda}/\Gamma_{\psi \to \rho\pi}$, (ii) $\sigma^{\phi}/\sigma^{\omega}$ production, and (iii) $\sigma_{pp \to}[\psi \to e^+e^-] + X/\sigma_{pp} \to e^+e^- + X$ at 30 GeV/c]. Here we do not wish to dwell on the actual existence of the O-meson family as real particles: the poles we use may merely be convenient approximations to or parametrizations of a cut in the forbidden amplitudes responsible for Zweig Rule violation. The O-meson intermediary, taken to be an SU(4) singlet and a Pomeron daughter, simply provides a definite q^2 dependence and relative strength of the $\psi \to \omega, \varphi$ off-shell transitions. The SU(4) symmetry is then broken in a natural way by mass differences in internal propagators.

In this note we will extend the idea of the O-meson as used in Refs. 4 and 5 from the $J^P = 1^-$ channel to the 0^+ channel. This will allow us to fix the scale of Zweig Rule violation in 0^+ decays, and to discuss a number of purely hadronic processes which involve the $c\bar{c}(0^+)$ state (which we will call ϵ_c). Some information on vector-vector-scalar couplings is also established. We then discuss certain hadronic branching ratios of the ψ which bear on its SU(3) character and test that aspect of the O-meson model. Finally we will use vector dominance and the vector-vector-scalar couplings previously determined to calculate a number of interesting γ-decays of the ψ, ψ', and ϵ_c.[6]

II. Basic Assumptions

(i) The couplings of the O-mesons are given by

$$\mathcal{L}_{OS} = \left(f_{O\epsilon}\epsilon + f_{OS^*}S^* + f_{O\epsilon_c}\epsilon_c\right) O(0^+)$$

$$\mathcal{L}_{OV} = \left(f_{O\omega}\omega^\mu + f_{O\varphi}\varphi^\mu + f_{O\psi}\psi^\mu\right) O_\mu(1^-). \qquad (1)$$

SU(4) symmetry and ideal mixing imply

$$f_{O\omega}/\sqrt{2} = f_{O\varphi} = f_{O\psi} \equiv f_{OV} \text{ and } f_{O\epsilon}/\sqrt{2} = f_{OS^*} = f_{O\epsilon_c} \equiv f_{OS}.$$

The O-mesons have masses between $\sqrt{2}$ and $\sqrt{3}$ GeV in accord with a linear

Pomeron trajectory with slope between 1/2 and 1/3.

(ii) $g_{\psi'\psi\epsilon_c} = \sqrt{2}\, g_{\rho'\rho\epsilon}$. This results if SU(4) symmetry is assumed for the V'VS coupling, with ρ' and ψ' assigned to the same ideally mixed SU(4) 15-plet and singlet. The decay $\rho' \to \rho[\epsilon \to 2\pi]$ implies $g^2_{\rho\rho'\epsilon}/4\pi = 5.6\ \mathrm{GeV}^{-2}$.

(iii) $g_{\psi'\psi'\epsilon_c} \approx g_{\psi\psi\epsilon_c} \approx g_{\psi'\psi\epsilon_c}$. All are Zweig Rule allowed vertices. [Together with SU(4) this implies $g_{\omega\omega\epsilon} = g_{\rho'\rho\epsilon}$.] Since we shall be using vector dominance for γ-decays, we use the tensor couplings[7]

$$\mathcal{L} = g_{\psi'\psi\epsilon_c}\left(\partial_\mu \psi'_\nu - \partial_\nu \psi'_\mu\right)\left(\partial^\mu \psi^\nu - \partial^\nu \psi^\mu\right)\epsilon_c . \tag{2}$$

(iv) At the $\epsilon\pi\pi$ vertex we use the chiral couplings[8]

$$\mathcal{L} = g_{\epsilon\pi\pi}\, \partial_\mu \vec{\pi} \cdot \partial^\mu \vec{\pi}\ \epsilon \tag{3}$$

with $g_{\epsilon\pi\pi}$ extracted from the $\epsilon \to 2\pi$ width. Taking $M_\epsilon = .7$ GeV and $\Gamma_{\epsilon\to\pi\pi} = .6$ GeV gives $g^2_{\epsilon\pi\pi}/4\pi = 24.05\ \mathrm{GeV}^{-2}$.

III. $\psi' \to \psi\pi^+\pi^-$ and $\psi \to \omega\pi\pi$

Figure 1a displays what we take for the dominant diagram for $\psi' \to \psi\pi^+\pi^-$. The decay amplitude is

$$T = g_{\psi\psi'\epsilon_c}\left(\partial^\mu \psi^\nu - \partial^\nu \psi^\mu\right)\left(\partial_\mu \psi'_\nu - \partial_\nu \psi'_\mu\right) g_{\epsilon\pi\pi} k_{1\lambda} \cdot k_2^\lambda \sqrt{2}\ f^2_{0S}$$

$$\times \left[\left(M^2_{\pi\pi} - M^2_{\epsilon_c}\right) + iM_{\epsilon_c}\Gamma_{\epsilon_c}\right]^{-1}\left[\left(M^2_{\pi\pi} - M^2_{\epsilon}\right) + iM_\epsilon\Gamma_\epsilon\right]^{-1}\left[\left(M^2_{\pi\pi} - M^2_0\right) + iM_0\Gamma_0\right]^{-1} \tag{4}$$

yielding a width

$$\Gamma_{\psi'\to\psi\pi\pi} = g^2_{\psi'\psi\epsilon_c}\ \frac{1}{24M'^3}\ g^2_{\epsilon\pi\pi}\ \frac{1}{(2\pi)^3}\ 2f^4_{0S} \int_{2\mu}^{(M'-M)} \rho(M_{\pi\pi}) \tag{5}$$

where $\rho(M_{\pi\pi})$, the dipion mass spectrum, is

$$\rho(x) = x\left(1 - \frac{4\mu^2}{x^2}\right)^{\frac{1}{2}}\left[x^4 - 2x^2(M^2 + M'^2) + (M'^2 - M^2)^2\right]^{\frac{1}{2}}$$

$$\times\left[(M'^2 + M^2 - x^2)^2 + 2M'^2M^2\right]\left(\frac{x^2}{2} - \mu^2\right)^2$$

$$\times\left[(x^2 - M_\epsilon^2)^2 + M_\epsilon^2\Gamma_\epsilon^2\right]^{-1}\left[(x^2 - M_{\epsilon_c}^2)^2 + M_{\epsilon_c}^2\Gamma_{\epsilon_c}^2\right]^{-1}\left[(x^2 - M_o^2)^2 + M_o^2\Gamma_o^2\right]^{-1} \tag{6}$$

with $M'(M)$ the mass of the $\psi'(\psi)$. We take the mass of the ϵ_c to be 3.5 GeV, thus identifying it with recently reported bumps in $\psi' \to \gamma + x$.[9] The spectrum is plotted in Fig.2, and seems to agree with reported data. The derivative pion coupling leads to peaking in the high mass region (or, perhaps, more to the point, leads to suppression of the soft pion region). The only other appreciable effects come from the O-pole parameters. Thus, the $\psi' \to \psi\pi\pi$ width is insensitive to the ϵ_c total width (within reasonable variation - $\Gamma_{\epsilon_c} \leq 50$ MeV) but does depend on the $O(0^+)$ total width. Taking $\Gamma_{\psi' \to \psi\pi^+\pi^-} =$ 70 kev, we find for $\Gamma_{O(0+)} = 1$ GeV, that

$$f_{OS} = .4032 \ (.4850) \quad \textit{for } m_O = \sqrt{2}\,(\sqrt{3}) \text{ GeV} \tag{7}$$

where we have guessed that the $O(0^+)$ is fairly broad (~ 1 GeV) compared to the $O(1^-)$ for the same reason that ϵ is broad compared to ρ; a consistency check is that with f_{OS} and Γ_O thus given we can calculate $\Gamma_{O(0^+)} \to 2\pi$ (via intermediate ϵ) and $\Gamma_{\epsilon_c} \to \pi\pi$. We find then that $\Gamma_{O(0^+)} \to 2\pi \approx .85$ GeV (but we expect this to be damped by off-shell coupling effects) and

$\Gamma_{\epsilon_c \to 2\pi}/\Gamma_{\psi \to \rho\pi} \approx 14 - 30.$

That f_{OS} is larger than f_{OV} as reported in Ref.4 implies that the scalar multiplet is more mixed (relative to ideal mixing) than the vector multiplet, with the mixing scale (e.g., that observed in $\varepsilon_c \to 2\pi$) set by

$$\frac{f_{OS}^2}{\left(m_{\varepsilon_c}^2 - m_0^2\right)\left(m_{\varepsilon_c}^2 - m_{\varepsilon}^2\right)} \tag{8}$$

The full implication of these mixings and their relation to a mass matrix will be discussed elsewhere.

The rate $\psi \to \omega[\varepsilon \to \pi\pi]$ is of interest here because it involves a test of assumption (iii) which we will use in the section on Υ-decays. The appropriate diagram is in Fig.1b. The partial rate is

$$\Gamma_{\psi \to \omega\varepsilon} = \frac{1}{3\pi} \frac{G_{\omega\omega\varepsilon}^2}{\left(M_\psi^2 - M_\omega^2\right)^2 + M_\omega^2 \Gamma_\omega^2} \frac{f_{OV}^4}{\left(M_\psi^2 - M_o^2\right)^2 + M_o^2 \Gamma_o^2} \, p\left(2p^2 + 3M_\omega^2\right) \tag{9}$$

where $p = \frac{1}{2M_\psi}\sqrt{\Lambda(M_\psi^2, M_\omega^2, M_\varepsilon^2)}$ is the decay momentum, Λ being the triangle function. Since the $\omega\omega\varepsilon$ vertex is evaluated far off shell, we minimize extrapolation effects by quoting the ratio

$$\frac{\Gamma_{\psi \to \omega\varepsilon}}{\Gamma_{\psi \to \rho\pi}} = \begin{cases} .60, & m_0^2 = 2 \\ .58, & m_0^2 = 3 \end{cases} \tag{10}$$

where $\Gamma_{\psi \to \rho\pi}$ has been calculated in Ref.4.

Recent data indicate a branching ratio for $\psi \to \omega\pi^+\pi^-$ of .8%. Including the $\pi^o\pi^o$ mode and assuming $I = 0$ for the $\pi\pi$ system, yields $\psi \to \omega\pi\pi$ branching ratio of 1.2%. Thus, experimentally,

$$\frac{\Gamma_{\psi \to \omega\epsilon}}{\Gamma_{\psi \to \rho\pi}} = \frac{(1.35\% \pm .45\%)x}{1.3\% \pm 0.3\%} = (1.04 \pm .54)x \tag{11}$$

where x is the fraction of the $I = 0$ $\pi\pi$ system that goes through the ϵ. The calculation is consistent with the data if $.4 < x < 1$. Without further data it is not possible to pin down x, but $\pi\pi$ phase shifts do indicate that ϵ is the most substantial contribution below 1 GeV and the D-wave, which is the next higher possible partial wave, is quite small below 1 GeV.[10] The ϵ contribution in this range, independent of what the phase shift does between 1 and 2 GeV, already indicates the x is substantial, so that our prediction, Eq.10, can not be far off. We thus feel that the assumption $g_{\omega\omega\epsilon} \approx g_{\rho'\rho\epsilon}$ is consistent with $\psi \to \omega\pi\pi$ data, and are encouraged that our broader assumption (iii) can not be far wrong. (The 2^+ D-wave contribution will be treated elsewhere.

IV. Hadronic Branching Ratios and the SU(3) Character of the $\psi(3095)$

A check on the SU(3) character of that small part of the ψ wave function which decays into ordinary hadrons is afforded by the branching ratios

$$\Gamma_{\psi \to \Lambda\bar{\Lambda}}/\Gamma_{\psi \to p\bar{p}} \qquad \text{and} \qquad \Gamma_{\psi \to K^+K^{-*}}/\Gamma_{\psi \to \pi^+\rho^-} \ .$$

In the O-meson dominated sequential decay calculated in Ref.5 (Figs. 1c,d and e) we have

$$\Gamma_{\psi \to \Lambda\Lambda} = \frac{M_\psi}{12\pi}\left(1 - \frac{4m_\Lambda^2}{M_\psi^2}\right)^{\frac{1}{2}}\left(1 + \frac{2m_\Lambda^2}{M_\psi^2}\right)\frac{f_{0\psi}}{(M_\psi^2 - M_0^2)}\left(\frac{f_{0\omega}g_{\omega\Lambda\bar{\Lambda}}}{(M_\psi^2 - M_\omega^2)} + \frac{f_{0\varphi}g_{\varphi\Lambda\bar{\Lambda}}}{(M_\psi^2 - M_\varphi)}\right)^2 \tag{12}$$

$$\Gamma_{\psi p\bar{p}} = \frac{M_\psi}{12\pi}\left(1 - \frac{4m_p^2}{M_\psi^2}\right)^{\frac{1}{2}}\left(1 + \frac{2m_p^2}{M_\psi^2}\right)\frac{f_{0\psi}^2}{(M_\psi^2 - M_0^2)^2}\left(\frac{g_{\omega p\bar{p}} f_{0\omega}}{(M_\psi^2 - M_\omega^2)}\right)^2 . \tag{13}$$

SU(3) implies

$$g_{\omega\bar{\Lambda}\Lambda} = \sqrt{2}\ g_{\varphi\Lambda\bar{\Lambda}} = \tfrac{2}{3}\ g_{\omega\bar{p}p}.$$

Thus the ratio is

$$\frac{\Gamma_{\psi\Lambda\bar{\Lambda}}}{\Gamma_{\psi p\bar{p}}} = \left\{\frac{\left(1 - \frac{4m_\Lambda^2}{M_\psi^2}\right)^{\frac{1}{2}}\left(1 + \frac{2m_\Lambda^2}{M_\psi^2}\right)}{\left(1 - \frac{4m_p^2}{M_\psi^2}\right)^{\frac{1}{2}}\left(1 + \frac{2m_p^2}{M_\psi^2}\right)}\right\}\left\{\frac{2}{3} + \frac{f_{0\varphi}}{f_{0\omega}}\frac{\sqrt{2}}{3}\frac{m_\psi^2 - m_\omega^2}{M_\psi^2 - M_\varphi^2}\right\}^2 \tag{14}$$

It should be noted that even when the 0-meson is taken to be an SU(4) [hence SU(3)] singlet [$f_{0\varphi} = f_{0\psi} = f_{0\omega}/\sqrt{2}$], SU(3) breaking is induced by the masses in the propagators. Calculating the phase space factors, we have

$$\frac{\Gamma_{\psi\to\Lambda\bar{\Lambda}}}{\Gamma_{\psi\to p\bar{p}}} = .928\ \left\{\frac{2}{3} + \frac{f_{0\varphi}}{f_{0\omega}}\frac{\sqrt{2}}{3}\frac{m_\psi^2 - m_\omega^2}{m_\psi^2 - m_\varphi^2}\right\}^2 \tag{15}$$

The data indicate[11]

$$\frac{\Gamma_{\psi\to\Lambda\bar{\Lambda}}}{\Gamma_{\psi\to\bar{p}p}} = .76 \pm .53. \tag{16}$$

If we take $\sqrt{2}\ f_{0\varphi}/f_{0\omega} = 1$, the SU(4) coupling, the prediction Eq.(15) is $\Gamma_{\psi\to\Lambda\bar{\Lambda}}/\Gamma_{\psi\to\bar{p}p} = .942$, in agreement with the data, within errors. The most favored experimental ratio (0.76) is reached only when $f_{0\varphi}\sqrt{2}/f_{0\omega} < 1$, suggesting that the ψ is more ω- than φ-like. Proceeding with this approach, we calculate the second ratio (proceeding via 0 through φ and ω)

$$\frac{\Gamma_{\psi \to K^+K^{*-}}}{\Gamma_{\psi \to \pi^+\rho}} = \{.84\} \left\{ \frac{1}{2} + \frac{1}{2} \frac{f_{0\varphi}\sqrt{2}}{f_{0\omega}} \frac{m_\psi^2 - m_\omega^2}{m_\psi^2 - m_\varphi^2} \right\}^2 \tag{17}$$

where again the first factor on the right is the phase space ratio, and the SU(3) coupling assumptions

$$G_{\varphi K^+K^{*-}} = \frac{G}{\sqrt{2}} \omega K^+K^{*-} = \frac{2}{\sqrt{2}} G_{\omega\pi^+\rho^-} \tag{18}$$

have been made.

The data indicate[10]

$$\frac{\Gamma_{\psi \to K^+K^{*-}}}{\Gamma_{\psi \to \pi^+\rho^-}} = .36 \pm .17 \tag{19}$$

whereas SU(4) coupling of the 0-meson in Eq.(17) predicts 0.88 for this ratio, in considerable disagreement with the data, again implying that ψ is more ω- than φ-like. The upshot of this seems to be that the ψ has a reluctance to decay into strange particles.

This is in qualitative agreement with data on the relative abundance of charged K vs. π mesons under and outside of the ψ peak. Outside of the peak, where the production is directly from the photon, which counts charges, one expects equal numbers of charged K and π-mesons, with the ratio lowered by kinematical and phase space effects, which favor pions. Under the ψ peak, where hadron production is mostly direct, one would again expect the number of K vs. number of π mesons to be equal <u>if the ψ decayed as an SU(3) singlet</u>, with the ratio then lowered by the same kinematical and phase space mechanism which operate outside the peak. Thus if the ψ decayed as an SU(3) singlet, one would expect no change of the K/π ratio as one passes through the peak, and a decrease if the ψ tended to be more ω-like than a singlet classification indicates.

In our model, in order to bring the $K^+K^{*-}/\pi^+\rho^-$ ratio to .53, the experimental upper limit, one requires $\sqrt{2}\ f_{0\varphi}/f_{0\omega} \sim .7$, which should be compared with $\sqrt{2}\ f_{0\varphi}/f_{0\omega} = 1$, the SU(3) singlet prediction.

V. γ-Decays

We consider first the decays $\psi(\psi') \to \pi\gamma$ proceeding through the diagram in Fig.1f. Assuming that $f_{0\psi'} \approx f_{0\psi}$, we have

$$\begin{aligned}
\Gamma_{\psi\to\pi\gamma} &= 8.9\ \text{eV} \qquad m_o = \sqrt{2}\ \text{GeV} \\
&\quad 47.4\ \text{eV} \qquad m_o = \sqrt{3} \\[1em]
\Gamma_{\psi'\to\pi\gamma} &= 4.5\ \text{eV} \qquad m_o = \sqrt{2} \\
&\quad 21.7\ \text{eV} \qquad m_o = \sqrt{3}
\end{aligned} \tag{20}$$

which is too small to be of much interest.

Recent reports of monochromatic γ-rays from DESY[9] imply the existence of at least one new state in the 3.5 GeV range. We will assume that it is the $J^P = 0^+(c\bar{c})$ that is, the ϵ_c invoked above in $\psi' \to \psi\pi\pi$.

Then we can calculate $\psi' \to \epsilon_c + \gamma$ using the diagram of Fig. 1g with the result

$$\Gamma_{\epsilon_c\to\gamma\psi} = \frac{G^2}{3\pi}\left(\sum_I \frac{F_{\gamma\psi_I}}{M^2_{\psi_I}}\right)^2\left(\frac{M^2_{\psi'}-M^2_{\epsilon_c}}{2M_{\psi'}}\right)^3 \tag{21}$$

where $\psi_I = \psi$ or ψ', and $G^2 = G_{\psi\psi\epsilon_c} \approx G_{\psi\psi'\epsilon_c} \approx G_{\psi'\psi'\epsilon_c}$, evaluated above, with $F_{\gamma\psi_I}$ the usual photon-vector meson junction. Using the leptonic decays of ψ

and ψ' to evaluate them,[11] we have

$$\Gamma_{\psi' \to \epsilon_c \gamma} = 15 \text{ keV}. \tag{22}$$

Similarly, the decay $\epsilon_c \to \gamma\psi$ is given by the diagram of Fig.1h, with the result

$$\Gamma_{\epsilon_c \to \gamma\psi} = \frac{G^2}{\pi}\left(\sum_I \frac{F_{\gamma\psi_I}}{M^2_{\psi_I}}\right)^2 \left(\frac{M^2_{\epsilon_c} - M^2_{\psi}}{2M_{\epsilon_c}}\right)^3 \approx 330.7 \text{ keV}. \tag{23}$$

($\Gamma_{\epsilon_c \to \gamma\psi}$ is larger than $\Gamma_{\psi' \to \epsilon_c\gamma}$ because of phase space and the final state spin degree of freedom.) Thus for the cascade partial width we have

$$\Gamma_{\psi' \to \gamma\epsilon_c \,\llcorner\!\to \gamma\psi} = \Gamma_{\psi'\epsilon_c\gamma} \frac{\Gamma_{\epsilon_c \to \gamma\psi}}{\Gamma_{\epsilon_c}} \quad . \tag{24}$$

The reported upper limit on $\psi' \to \gamma\gamma\psi$ is 6.6 keV,[11] of which 4 ± 2 keV is $\psi' \to \psi\eta$.[11] Then experimentally,

$$\Gamma_{\psi' \to \gamma\epsilon_c \,\llcorner\!\to \gamma\psi} \leq 2.6 \pm 2 \text{ keV}.$$

Thus our calculation is consistent with the data if

$$\Gamma_{\epsilon_c} \geq 1 - 8 \text{ MeV}. \tag{25}$$

VI. Summary

We have studied the decays $\psi' \to \psi\pi\pi$ and $\psi \to \omega\epsilon$, and concluded that they can be understood using conventional strong interaction decay dynamics plus the suppression mechanism of the O-meson. We have commented on the SU(3) classification of the decay of ψ into ordinary hadrons; withing the framework of our model the ψ seems to have more ω-content than an SU(3) singlet ($\sqrt{2}\,\omega+\varphi$) classification would require. Finally, we calculated the cascade decay of ψ', using couplings inferred from the $\psi' \to \psi\pi\pi$ and $\psi \to \omega\epsilon$ decays. The results are consistent with the present experimental situation.

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Figure Captions

Fig.1. Pole diagrams for

(a) $\psi' \to \psi\pi^+\pi^-$ via ϵ, ϵ_c and $O(0^+)$

(b) $\psi \to \omega\pi\pi$ via ϵ, ω and $O(1^-)$

(c) $\psi \to \bar{\Lambda}\Lambda$ via ω and $O(1^-)$

(d) $\psi \to \bar{\Lambda}\Lambda$ via φ and $O(1^-)$

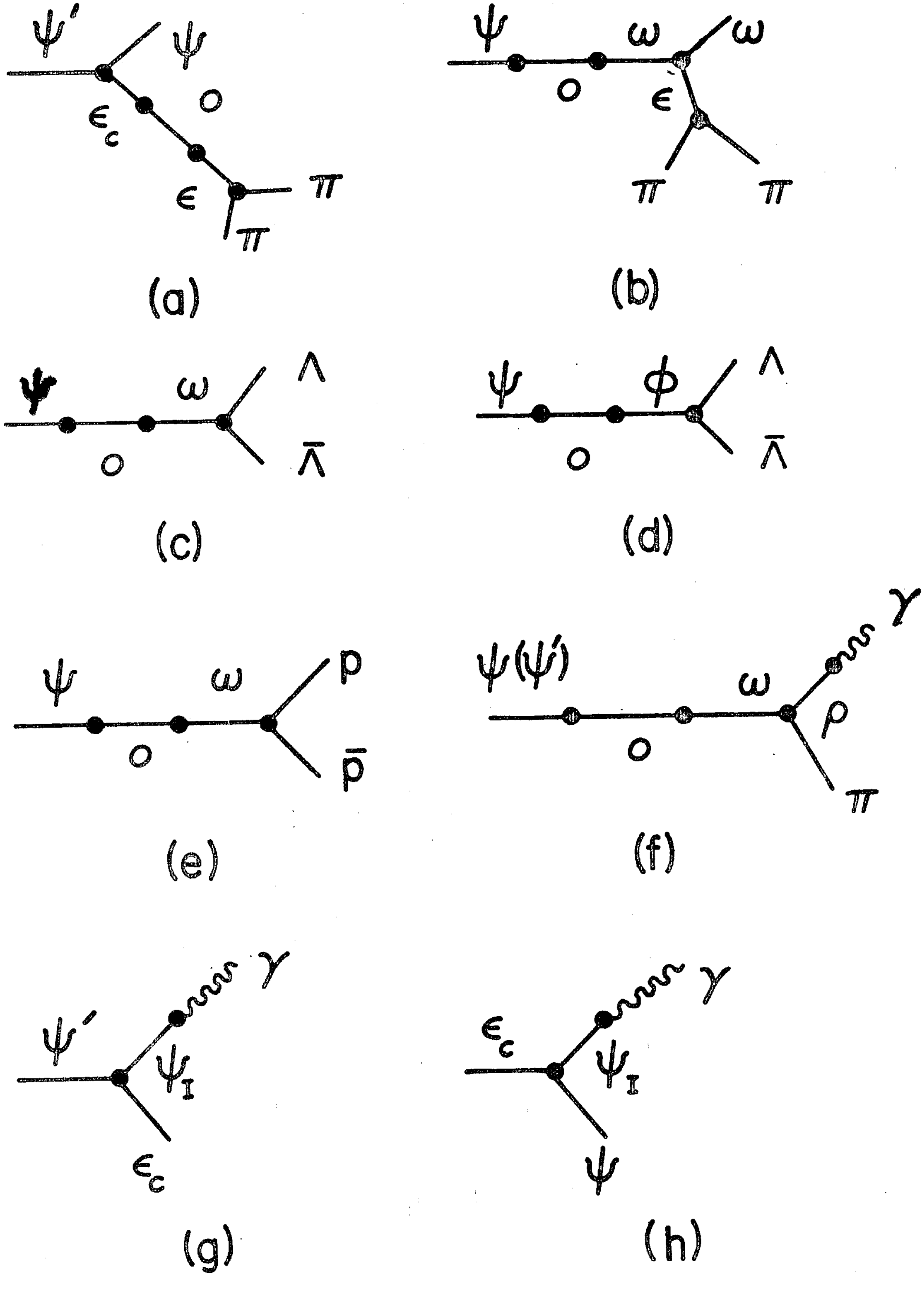
(e) $\psi \to \bar{p}p$ via ω and $O(1^-)$

(f) $\psi(\psi') \to \gamma\pi$ via ω, ρ and $O(1^-)$

(g) $\psi' \to \gamma\epsilon_c$ via ψ and ψ'

(h) $\epsilon_c \to \gamma\psi$ via ψ and ψ'

Fig.2. $M_{\pi\pi}$ mass distribution as calculated via the O-meson model and data from Ref.10.



ψ'
ψ
o
ε_c
ε
π
π
(a)
ψ
ω
ω
o
ε
π
π
(b)
ψ
ω
Λ
o
Λ̄
(c)
ψ
φ
Λ
o
Λ̄
(d)
ψ
ω
p
o
p̄
(e)
ψ(ψ')
ω
γ
ρ
o
π
(f)
ψ'
γ
ψ_I
ε_c
(g)
ε_c
γ
ψ_I
ψ
(h)

FIG. 1

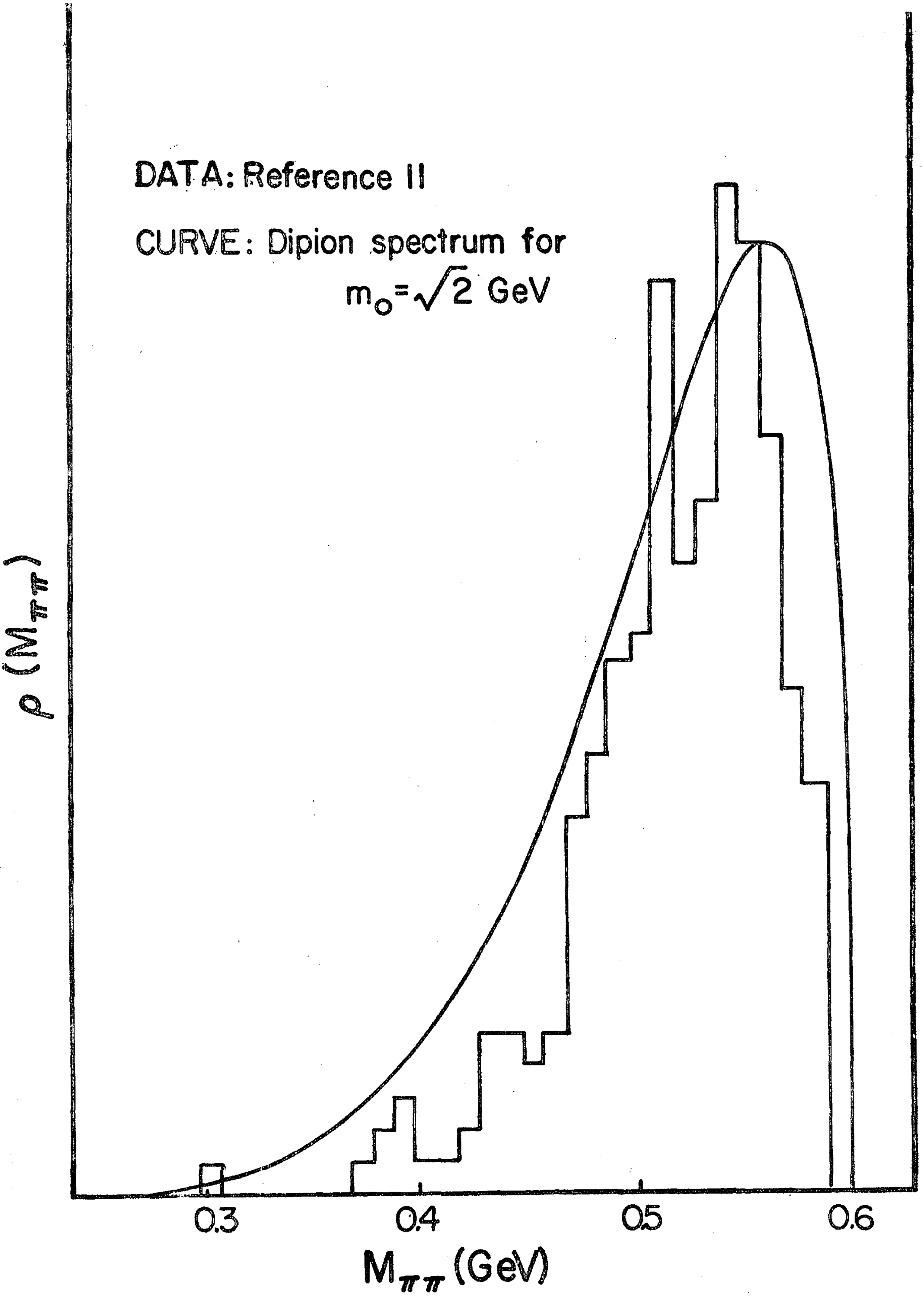

DATA: Reference 11
CURVE: Dipion spectrum for
$m_0 = \sqrt{2}$ GeV
$\rho\,(M_{\pi\pi})$
0.3
0.4
0.5
0.6
$M_{\pi\pi}$ (GeV)

FIG. 2