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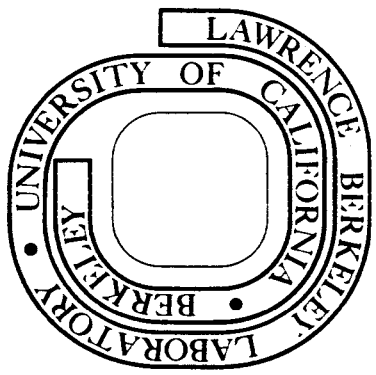

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DISCLAIMER

PRODUCTION OF CHARMED MESON PAIRS IN ELECTRON-POSITRON ANNIHILATION

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ABSTRACT

Production of charmed meson pairs of $J^P = 0^-$ and 1^- is examined near the threshold. Production cross sections are parametrized by a quark model of a broken SU(8) symmetry. The charmed hadron production is dominated by $(0^-,1^-)$ pairs, and $D^*\bar{D}^*$ production comes out to be much too small to reproduce the higher peak in the recoil mass spectrum against D^0 $(\bar{D}^0)$ through reflection. We point out a few experimental measurements that will clarify the origin of the higher peak of the recoil mass spectrum.

I. INTRODUCTION

Conclusive evidences for charmed mesons have finally arrived in the e^+e^- annihilation at SPEAR.[1,2] The strongest signature has been seen near the thresholds of two-body production. In the present paper we examine pair production of charmed mesons with $J^P = 0^-$ and 1^- by means of a badly broken SU(8) symmetry, supplemented with quark model considerations when necessary. The two-body production

cross sections near one of the broad resonances are parametrized by two numbers that are locally energy-independent. The charmed quark pair coupling alone leads us to the ratios for reduced cross sections $\bar{\sigma} = (|\underline{p}|/E)^{-3}\sigma$ as

$$\bar{\sigma}(D\bar{D}) \;:\; \bar{\sigma}(D\bar{D}^*) \;:\; \bar{\sigma}(D^*\bar{D}^*) \;=\; 1 : 3.4 : 19 \,, \qquad (1.1)$$

where $|\underline{p}|$ is the momentum of the final charmed mesons and E is the electron beam energy. Although these ratios improve the fit to experiment as compared with those of the simple quark spin weight model $(1 : 2 : 7)$,[3] $\bar{\sigma}(D^*\bar{D}^*)$ still comes out to be too small to reproduce the higher peak in the recoil mass against $D^0(\bar{D}^0)$ through reflection. The interference with the light quark contribution in the production may help to improve some aspects, but the overall fit to the three production cross sections cannot be improved significantly. A few interesting phenomena are pointed out in the presence of a sizable interference. Energy dependence of the cross section ratio may provode a clue for understanding the dynamical mechanism of the charmed meson production. It is pointed our that the higher peak in the recoil mass may be due to $D\bar{D}^{**}$ (1^+) production.

II. PARAMETRIZATION

The coupling of a photon with $(0^-,0^-)$, $(0^-,1^-)$, and $(1^-,1^-)$ is written as[4]

$$(p - p')_\mu \{F_q^{(1)}(q^2) + F_c^{(1)}(q^2)\} \quad \text{for } (0^-,0^-), \quad (2.1)$$

$$\epsilon_{\mu\nu\lambda\kappa}\, \epsilon^\nu p^\lambda q^\kappa \{F_q^{(2)}(q^2) + F_c^{(2)}(q^2)\} \quad \text{for } (0^-,1^-), \quad (2.2)$$

$$\begin{aligned}
&(p - p')_\mu (\epsilon_\nu \epsilon'^\nu) \{G_q^{(1)}(q^2) + G_c^{(1)}(q^2)\} \\
&+ \{(\epsilon_\nu p'^\nu)\epsilon'_\mu - (\epsilon'_\nu p^\nu)\epsilon_\mu\} \\
&\times \{G_q^{(1)}(q^2) + G_c^{(1)}(q^2) + G_q^{(2)}(q^2) + G_c^{(2)}(q^2) + G_q^{(3)}(q^2) + G_c^{(3)}(q^2)\} \\
&+ (p - p')_\mu \{-(\epsilon_\nu p'^\nu)(\epsilon'_\lambda p^\lambda) + \tfrac{1}{2} q^2 (\epsilon_\mu \epsilon'^\mu)\} \{G_q^{(3)}(q^2) + G_c^{(3)}(q^2)\}/m_\rho^2
\end{aligned}$$

$$\text{for } (1^-,1^-), \quad (2.3)$$

where the kinematics is shown in Fig. 1. $F_q^{(1)}$ and $G_c^{(1)}$ are the form factors of the charge coupling, and their subscripts indicate whether the photon couples with the light quark q or the charmed quark c. Similarly $F_q^{(2)}$ and $G_c^{(2)}$ are the form factors of the magnetic dipole coupling, and $G^{(3)}$ is the form factor of the electric quadrupole coupling. A few dynamical assumptions are introduced here to parametrize them.

Normalization

The charge form factors are normalized at $q^2 = 0$ according to the fractional quark charges,

$$F_q^{(1)}(0) = G_q^{(1)}(0) = e\,Q_q \quad (Q_q = 2/3, -1/3, \text{ and } -1/3 \text{ for } u, d, \text{ and } s), \quad (2.4)$$

$$F_c^{(1)}(0) = G_c^{(1)}(0) = -e\,Q_c \quad (Q_c = 2/3). \quad (2.5)$$

The magnetic form factors are fixed at $q^2 = 0$ through the nonrelativistic $SU(8)$ symmetry.[5] However, we have to take into account a possible large $SU(4)$ breaking due to $m_c \gg m_q$. Unlike the charge,

the magnetic moment has the dimension of inverse mass and the magnetic moment of the charmed quark is quite different from that of the proton quark. Comparison of the radiative decays $\rho \to \pi\gamma$ and $\psi(3.1) \to \eta_c\gamma$ would give us a guide as to how a large breaking should be introduced. In the static quark model the magnetic dipole transitions occur through the quark magnetic moment $\frac{1}{2}Q/m$. With $m_q \simeq \frac{1}{2}m_\rho$, the $\rho \to \pi\gamma$ (or better $\omega \to \pi\gamma$) rate is reproduced accurately.[6] In this picture the $\psi\eta_c\gamma$ coupling is modified by $SU(4)$ breaking as

$$F_c^{(2)}(0) = \frac{m_q}{m_c} \left(\frac{F_c^{(2)}(0)}{F_q^{(2)}(0)}\right)_{SU(4)} F_q^{(2)}(0), \quad (2.6)$$

and similarly for $G_c^{(2)}(0)$. On the other hand, if one introduces the $SU(4)$ breaking into $SU(8)$ symmetric couplings through the vector meson masses, one would obtain

$$F_c^{(2)}(0) = \frac{m_\rho}{m_\psi} \left(\frac{F_c^{(2)}(0)}{F_q^{(2)}(0)}\right)_{SU(4)} F_q^{(2)}(0) \quad (2.7)$$

Note that $m_\rho \simeq 2m_q$ and $m_\psi \simeq 2m_c$. Equation (2.6) and (2.7) lead us to the same result. We therefore take into account the abnormal smallness of the charmed quark magnetic moment by the following normalizations:

$$F_q^{(2)}(0) = \frac{2}{m_\rho} Q_q, \quad (2.8)$$

$$F_c^{(2)}(0) = \frac{2}{m_\psi} Q_c, \quad (2.9)$$

$$G_q^{(2)}(0) = 3\,Q_q, \quad (2.10)$$

$$G_c^{(2)}(0) = -\frac{3m_\rho}{m_\psi} Q_c, \quad (2.11)$$

where there is no minus sign on the right hand side of (2.9) since the coupling is of the D type instead of the F type as charge conjugation invariance requires. The numerical factor 3 in (2.10) and (2.11) is a consequence of SU(8), but it is explained most naturally in the static quark model, too. To determine the quadrupole moments, one needs more than the nonrelativistic SU(8) or quark model. We determine them by the relativistic SU(8) or $\tilde{U}(16)$.[7] They are also subject to large SU(4) breaking. Following an argument similar to that for the magnetic moment, we introduce an SU(4) breaking factor into $G^{(3)}(0)$ as

$$G_q^{(3)}(0) = -\frac{1}{m_\rho^2} Q_q \quad , \tag{2.12}$$

$$G_c^{(3)}(0) = \frac{1}{m_\psi^2} Q_c \quad . \tag{2.13}$$

The suppression of the electric quadrupole moment $G_c^{(3)}(0)$ relative to $G_q^{(3)}(0)$ represents the fact that the charmed quark spreads far less from the center of mass of a physical meson than the light quark does.

Energy dependence of form factors

The form factors should be real or almost real in a region sufficiently away from resonances. In the region where the charmed meson pair production has been measured intensively, this is probably the case for the light quark form factors $F_q(q^2)$ and $G_q(q^2)$. The Okubo-Zweig-Iizuka rule forbids ψ resonances from entering $F_q(q^2)$ and $G_q(q^2)$. We therefore assume here that all of the light quark form factors are real in the energy region relevant to us. Their q^2 dependences are chosen to be common. The situation is opposite for

the charmed quark form factors. In order to enhance the charmed meson production channels, the measurement has been done at or near one of the broad ψ resonances. $F_c(q^2)$ and $G_c(q^2)$ are to be written there as

$$\sum_j \frac{c_j}{\{s - M_j^2 + i M_j \Gamma_j(s)\}} + (c\bar{c} \text{ background}) , \tag{2.14}$$

where $s = q^2$ and M_j is the j-th ψ resonance with width Γ_j. As is usual, the width in the Breit-Wigner formula is modified as

$$\Gamma_j(s) = \{p(s) / p(M_j^2)\}^3 \Gamma_j \quad , \tag{2.15}$$

where $p(s)$ is the center-of-mass momentum of a two-body channel.

III. CROSS SECTIONS NEAR A BROAD ψ RESONANCE

We write the formulae for total cross sections for production of charmed meson pairs.

0^-0^-

$$\sigma(s) = \frac{\alpha |f(s)|^2}{12s} \beta^3 \quad , \tag{3.1}$$

or

$$R(s) = \{|f(s)|^2 / e^2\} \beta^3 \quad , \tag{3.2}$$

where $\beta = |p| / E$ of the charmed meson,

$$f(s) = \begin{cases} \frac{1}{3} F(s) \{-1 - 2a(s)\} & \text{for } D^+D^- , \quad (3.3) \\ \frac{1}{3} F(s) \{2 - 2a(s)\} & \text{for } D^0\bar{D}^0 , \quad (3.4) \\ \frac{1}{3} F(s) \{-1 - 2a(s)\} & \text{for } F^+F^- . \quad (3.5) \end{cases}$$

$F(s)$ is the light quark form factor normalized as $F(0) = 1$, and $a(s)$ is the ratio of $F_c(q^2)/F_q(q^2)$ normalized as $a(0) = 1$. Near a ψ resonance, $a(s)$ is given by one of the Breit-Wigner terms in (2.14).

0^-1^- and 1^-0^-

$$\sigma(s) = \frac{\alpha|f(s)|^2}{24m_\psi^2}\left(\frac{|\underset{\sim}{p}|}{E}\right)^3 , \qquad (3.6)$$

or

$$R(s) = \tfrac{1}{2}\{|f(s)|^2/e^2\}\{s/m_\psi^2\}\ \{|\underset{\sim}{p}|/E\}^3 , \qquad (3.7)$$

where E is the initial electron beam energy,

$$f(s) = \begin{cases} \frac{2}{3}F(s)\,(-1 + 2a(s)\,\kappa) & \text{for } D^+D^-, \quad (3.8) \\ \frac{2}{3}F(s)\,(\ 2 + 2a(s)\,\kappa) & \text{for } D^0\bar{D}^0, \quad (3.9) \\ \frac{2}{3}F(s)\,(-1 + 2a(s)\,\kappa) & \text{for } F^+F^-, \quad (3.10) \end{cases}$$

and $\kappa \equiv m_\rho/m_\psi$, which is approximately equal to m_q/m_c numerically. We have ignored small mass difference between $D^*(1^-)$ and $F^*(1^-)$. The same $F(s)$ and $a(s)$ appear here as in the $(0^-,0^-)$ production by our assumption on the form factors.

1^-1^-

$$\sigma(s) = \frac{\alpha}{12s}\ \{4\gamma^2|A(s)|^2 + 2|B(s)|^2 + |C(s)|^2\}\beta^3 , \qquad (3.11)$$

or

$$R(s) = \frac{1}{e^2}\ \{4\gamma^2|A(s)|^2 + 2|B(s)|^2 + |C(s)|^2\}\beta^3, \qquad (3.12)$$

where $\beta = |\underset{\sim}{p}|/E$, $\gamma = (1 - \beta^2)^{-\frac{1}{2}}$, and

$$A(s) = \begin{cases} \frac{1}{3}F(s)\left[-3 - 2a(s)\,\{1 + 3\kappa - \kappa^2\}\right] & \text{for } D^{+*}D^{-*}, \\ \frac{1}{3}F(s)\left[\ 6 - 2a(s)\,\{1 + 3\kappa - \kappa^2\}\right] & \text{for } D^{0*}\bar{D}^{0*}, \\ \frac{1}{3}F(s)\left[-3 - 2a(s)\,\{1 + 3\kappa - \kappa^2\}\right] & \text{for } F^{+*}F^{-*}, \end{cases} \qquad (3.13)$$

$$B(s) = \begin{cases} \frac{1}{3}F(s)\left[-1 + 2\gamma^2 - 2a(s)\,\{1 - 2\gamma^2\kappa^2\}\right] & \text{for } D^{+*}D^{-*}, \\ \frac{1}{3}F(s)\left[\ 2 - 4\gamma^2 - 2a(s)\,\{1 - 2\gamma^2\kappa^2\}\right] & \text{for } D^{0*}\bar{D}^{0*}, \\ \frac{1}{3}F(s)\left[-1 + 2\gamma^2 - 2a(s)\,\{1 - 2\gamma^2\kappa^2\}\right] & \text{for } F^{+*}F^{-*}, \end{cases} \qquad (3.14)$$

$$C(s) = \begin{cases} \frac{1}{3}F(s)\left[-1 - 6\gamma^2 - 2a(s)\,\{1 + 6\gamma^2\kappa\}\right] & \text{for } D^{+*}D^{-*}, \\ \frac{1}{3}F(s)\left[\ 2 + 12\gamma^2 - 2a(s)\,\{1 + 6\gamma^2\kappa\}\right] & \text{for } D^{0*}\bar{D}^{0*}, \\ \frac{1}{3}F(s)\left[-1 - 6\gamma^2 - 2a(s)\,\{1 + 6\gamma^2\kappa\}\right] & \text{for } F^{+*}F^{-*}. \end{cases} \qquad (3.15)$$

When we examine a narrow range of energy around one of the ψ resonances, we may assume that $F(s)$ is independent of s and $a(s)$ is of the form of $c\{s - M^2 + iM\Gamma(s)\}^{-1}$. We are left with two parameters, which should be determined by experiment.

IV. PRODUCTION AROUND A RESONANCE JUST ABOVE THRESHOLD

The most extensive search has been made for the charmed meson pair production at $\sqrt{s} = 4.028$ GeV, where a fairly narrow ψ resonance ($\Gamma \simeq 15 \sim 20$ MeV) exists. This is the energy region suitable for the search since the resonance enhances the yields and the two-body channels are still dominant.

We take the following values for masses;[1,2]

$$\begin{aligned} m_{D^+} &= 1871 \text{ MeV}, \\ m_{D^0} &= 1866.5 \text{ MeV}, \\ m_{D^{+*}} &= 2012 \text{ MeV}, \\ m_{D^{0*}} &= 2005.4 \text{ MeV}. \end{aligned} \tag{4.1}$$

The masses for D^+, D^0, and D^{0*} are based on the actual measurement, and the D^{+*} mass is half experimental and half theoretical. For F and F^*, the results are very sensitive to their masses.

$c\bar{c}$ dominance

Let us start with the case where the charmed meson production comes entirely through $c\bar{c}$ pairs. We can calculate cross section values in this case by letting $F(s) \to 0$ with $F(s)a(s)$ kept nonzero in the foregoing formulae. With the masses as given in (4.1) and $\sqrt{s} = 4028$ MeV, we can estimate uniquely the production cross section ratios as tabulated in Table 1A. The cross sections are normalized with respect to $\sigma(D^0\bar{D}^{0*}) + \sigma(\bar{D}^0 D^{0*})$ there. The production cross section for $F\bar{F}$ is obtained from that of either D^+D^- or $D^0\bar{D}^0$ by multiplying the ratios of p^3.

The $D^0\bar{D}^{0*}$ and $\bar{D}^0 D^{0*}$ channels clearly dominate in this case. But, the D^+D^- and $D^0\bar{D}^0$ productions are sizable, though not in an obvious disagreement with experiment. The production of $D^{0*}\bar{D}^{0*}$ pairs comes out to be too small simply because of the vanishingly small β^3 ($\sim 7.9 \times 10^{-4}$). So is the $D^{+*}D^{-*}$ production. This is clearly in contradiction to experiment if one attributes the higher peak of the recoil mass to the $D^{0*}\bar{D}^{0*}$ reflection. The $D^{0*}\bar{D}^{0*}$ cross

section is sensitive to the Q value. The values of masses quoted in (4.4) are subjected to statistical errors of 4 MeV and their systematic errors due mainly to the beam energy are $\simeq 5$ MeV. To show the sensitivity of the cross sections to the Q values, we have chosen another set of values for D^0 and D^{0*} masses as[8]

$$\begin{aligned} m_{D^0} &= 1862.5 \text{ MeV}, \\ m_{D^{0*}} &= 1998 \text{ MeV}. \end{aligned} \tag{4.2}$$

The results are tabulated in Table 1B. The production cross section for $D^{0*}\bar{D}^{0*}$ is still smaller than what has been observed in the experiment, if one tries to interpret the higher peak in the recoil mass against D^0 ($\bar{D}^0$) through the $D^{0*}\bar{D}^{0*}$ reflection.

For the sake of comparison with other model calculations, we give the cross section ratios of the case of degenerate masses:

$$\left.\begin{aligned} \sigma(D^0\bar{D}^0) &= \sigma(D^+D^-), \\ \sigma(D^0\bar{D}^{0*}) &= \sigma(D^+D^{-*}), \\ \sigma(D^{0*}D^{0*}) &= \sigma(D^{+*}D^{-*}), \end{aligned}\right\} \tag{4.3}$$

$$\begin{aligned} \sigma(D^0\bar{D}^0) : \sigma(D^0\bar{D}^{0*}) : \sigma(D^{0*}\bar{D}^{0*}) \\ = 1 : 2s/m_\psi^2 : 4\gamma^2(1+3\kappa-\kappa^2)^2 + 2(1-2\gamma^2\kappa^2)^2 + (1+6\gamma^2\kappa)^2, \end{aligned} \tag{4.4}$$

where $\gamma^2 = s/m_{D^*}^2$. If we set here roughly $m_\psi \simeq 2m_{D^*}$ in $\sigma(D^0\bar{D}^{0*})$ and $\kappa = 0$, namely $m_c \gg m_{u,d,s}$, the ratios in (4.4) reduce to 1 : 2 : 7 at the threshold $\sqrt{s} = 2m_{D^*}$. This agrees with the predictions of simple dynamical models based on spin weight.[3] In our model, the ratios are modified by $m_\psi \neq 2m_{D^*}$ and more sensitively by $\kappa \neq 0$.

The magnetic moments of D^*'s enhance considerably the $D^*\bar{D}^*$ production cross sections. At $\sqrt{s} \simeq 4$ GeV, the ratios in (4.4) become approximately equal to 1 : 3.4 : 19. Although this improves a fit to the experiment by a factor of two relative to the ratios 1 : 2 : 7, the improvement does not seem to be sufficient.

Light quark contribution

There is no reason to exclude the possibility that the light quark coupling with the time-like photon produces also the charmed mesons, too. At $\sqrt{s} = 4.028$ GeV, the broad resonance accounts most of the production, but the light quark contribution may not be negligible. We should like to call attention to a very similar situation near and above the $K\bar{K}$ threshold. As $\sqrt{s}$ goes beyond the $K\bar{K}$ threshold, $K\bar{K}$ pairs are produced through $s\bar{s}$ pairs. If all of the events containing $K\bar{K}$ come from the $s\bar{s}$ pairs, the fraction of events containing the K mesons would be given by

$$r \equiv \{\text{Events with } K(\bar{K})\} / \{\text{Total events}\} = 1/6 \qquad (4.5)$$

according to the asymptotic freedom. However, this K event fraction has been measured to be approximately equal to 20% for a K^- meson below $\sqrt{s} = 3$ GeV, and the fraction for a K_s meson is also about the same with less accuracy.[9] We therefore have

$$r \simeq 0.40 \qquad (4.6)$$

experimentally. Since the OZI rule predicts that $s\bar{s}$ pairs always end up with events with $K\bar{K}$, more than a half of the K events must originate from $u\bar{u}$ and $d\bar{d}$ pairs. With the experimentally

measured $R = 2.5$, we find that

$$\begin{aligned} &R(u\bar{u}, d\bar{d} \to \text{no } K\bar{K}) \simeq 1.5 , \\ &R(u\bar{u}, d\bar{d} \to \text{events with } K\bar{K}) \simeq 2/3 , \\ &R(s\bar{s} \to \text{events with } s\bar{s}) \simeq 1/3 . \end{aligned} \qquad (4.7)$$

It is therefore not out of the question to expect that the light quark pairs also produce the charmed mesons above $\sqrt{s} \simeq 4$ GeV.

We shal first enumerate qualitative consequences of the presence of the light quark contribution in the production of the charmed mesons.

(1) The light quark for factor $F(s)$ is probably real or almost real while the charmed quark form factor $a(s)F(s)$ is complex as descirbed by the Breit-Wigner formula. On the top of the resonance (4.03 GeV), therefore, the interference between the light quark and heavy quark contributions is unimportant. The production cross sections are not much affected by the presence of the light quark contribution unless it is comparable with the $c\bar{c}$ contribution.

(2) Off the resonance, however, the two contributions interfere to skew the Breit-Wigner shape of the cross sections. The abnormally steep rise of the total cross section on the lower side of the 4.03 GeV peak might have something to do with the interference effect. The interference is most significant in the $(0^-,1^-)$ production cross sections since the light quark contribution is enhanced relative to the charmed quark contribution by the ratio of the magnetic moment, κ^{-1}.

(3) The presence of the interference is best tested by measuring the production cross section ratios of charged pairs to neutral pairs. As we have seen in Section III, if the interference is constructive in D^+D^-, D^+D^{-*}, and $D^{+*}D^{-*}$, it is destructive in $D^0\bar{D}^0$, $D^0\bar{D}^{0*}$, and $D^{0*}\bar{D}^{0*}$. The ratios would be sensitive to the center of mass energy across the resonance peak.

(4) It does not seem possible to alter substantially the ratio of the $(0^-,0^-)$ to $(1^-,1^-)$ cross section by introducing a small phase into the light quark form factor $F(s)$: Such a phase tends to either enhance or suppress both of the cross sections at the same time, while the $(0^-,1^-)$ production cross section changes in an opposite way. If one assumes that the 4.03 GeV peak is not a genuine resonance, the charmed quark form factor is almost real so that a large interference is expected to occur. However, this does not help to improve the general trend of the cross section ratio.

To give an idea of what happens in the presence of the light quark contribution, we have performed a numerical calculation for the two cases in which the light and heavy quark contributions to $\sigma(D^0\bar{D}^{0*}) + \sigma(\bar{D}^0 D^{0*})$ are in the ratios of 1 : 3 and 1 : 5 at the peak of the 4.03 GeV resonance. From (2.14) and (3.9), these correspond to $(c\kappa/M\Gamma)^2$ equal to 3 and 5, respectively. Introducing $\kappa = m_\rho/m_\psi$ and Γ = 20 MeV, and assuming that the non-resonant light quark form factor $F(s)$ is constant over the narrow range in $\sqrt{s}$ considered, the results obtained are exhibited in Fig. 2(a) and 2(b). Away from the resonance peak the interference

between the two contributions distort the Breit-Wigner resonance shapes. The positive values for c taken result in a destructive interference in the lower side of the resonance and a constructive interference in the higher side. These behaviors are consistent with the experimental o servation near the 4.03 resonance. The above trend is reversed for the negative values of c. Evidently, the larger the above ratio, the more dominant $\sigma(D^0\bar{D}^{0*}) + \sigma(\bar{D}^0 D^{0*})$ becomes relative to $\sigma(D^0\bar{D}^0)$. In the present scheme the fact that experimentally the signature for $D^0\bar{D}^0$ production is almost vanishingly weak in comparison to that for $D^0\bar{D}^{0*} + \bar{D}^0 D^{0*}$ production indicates that the coupling of the resonant charmed quark pair is much stronger than that of the nonresonant light quark pair. However, $\sigma(D^{0*}\bar{D}^{0*})$ turns out to be too small in comparison to $\sigma(D^0\bar{D}^{0*}) + (\bar{D}^0 D^{0*})$ to reproduce the higher peak in the recoil mass against $D^0(\bar{D}^0)$ through reflection.

V. DISCUSSION AND SUMMARY

We have found that if $\psi(4.03)$ behaves like a member of the representation of SU(8), the ratio of two-body production cross sections does not seem to agree with the measurement. Our model reduces in a certain limit to the simple quark model based on spin weight, which leads us to even a worse disagreement with experiment. We can think of two distinct possibilities for this discrepancy, particularly, in the $D^*\bar{D}^*$ production cross section. The first possibility is that the abnormally large $D^*\bar{D}^*$ cross section occurs only at the peak of $\psi(4.03)$. In this case, we must conclude that $\psi(4.03)$ is something quite different in dynamical structure from the lower ψ's such as $\psi(3.1)$ and $\psi'(3.7)$. For instance, $\psi(4.03)$

might be a bound state of $c\bar{c}q\bar{q}$ instead of $c\bar{c}$,[10] in which case our results are expected to be valid at values of $\sqrt{s}$ away from the $\psi(4.03)$ peak. The second possibility is that the ratios of the reduced cross sections remain more or less the same off $\sqrt{s} = 4.03$ GeV. If this is the case, it would mean that we have to look for the origin of failure somewhere else, in particular, in the interpretation of the higher recoil peak against D^0 ($\bar{D}^0$) as the $D^{0*}\bar{D}^{0*}$ reflection. It is therefore very important to know how the ratio of the reduced cross sections varies as the energy is varied near $\sqrt{s} = 4.03$ GeV.

The other interesting problem is how much the light quark pairs contribute to the charmed meson production. This is most sensitively detected by measuring the ratio of the reduced cross sections such as $\bar{\sigma}(D^+D^-)/\bar{\sigma}(D^0\bar{D}^0)$, $\bar{\sigma}(D^+D^{-*})/\bar{\sigma}(D^0\bar{D}^{0*})$, and $\bar{\sigma}(D^{+*}D^{-*})/\bar{\sigma}(D^{0*}\bar{D}^{0*})$. What is actually measured in experiment is a product (decay branching ratio) × (production cross section). When we do not know decay branching ratios, we should look at the energy dependence of the cross sections. For instance, from (3.3) and (3.4), we find that

$$\bar{\sigma}(D^+D^{-*})/\bar{\sigma}(D^0\bar{D}^{0*}) = \frac{1}{4}\left(\frac{s - M^2 + 2c\kappa + iM\Gamma(s)}{s - M^2 - c\kappa + iM\Gamma(s)}\right)^2 . \qquad (5.1)$$

The interference is opposite between D^+D^{-*} and $D^0\bar{D}^{0*}$ so that, by measuring the ratio

$$\{B(D^+ \to K^-\pi^+\pi^+)\,\bar{\sigma}(D^+D^{-*})\}/\{B(D^0 \to K^-\pi^+)\,\bar{\sigma}(D^0\bar{D}^{0*})\} \qquad (5.2)$$

at different energies across the $\psi(4.03)$ peak, one can detect the presence of the light quark contribution through the rapid energy variation of the ratio (5.2). This gives another justification for measuring energy dependence of production cross sections near one of the broad ψ resonances.

To conclude this paper, we would like to propose an alternative explanation of the higher recoil peak against $D^0(\bar{D}^0)$. The only natural way to overcome the vanishingly small Q value for these events seems to be that D^0 and $\bar{D}^{0**}$ of $J^P = 1^+$ are produced in pair in an s-wave. Since β is about 0.1, with the values of masses given by experiment the cross section is enhanced by almost a hundred. This produces naturally the size of cross section that is needed to explain the higher recoil peak. Because of the difference in final partial waves (s-wave vs. p-wave), the relative heights of the two peaks in the recoil mass spectrum against $D^0(\bar{D}^0)$ would vary markedly as the energy is varied in nonresonant region.

VI. ACKNOWLEDGEMENT

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FIGURE CAPTIONS

Figure 1: Kinematics of photon vertices

Figure 2: Relative cross sections for (a) $(c\kappa/M\Gamma)^2 = 3$ and (b) $(c\kappa/M\Gamma)^2 = 5$. The values for the masses are as given in (4.2) in the text. The cross sections are given in arbitrary scales. The three curves, I, II, and III, represent the cross sections for $D^{o}\bar{D}^{o}$, $D^{o}\bar{D}^{o*} + \bar{D}^{o}D^{o*}$, and $D^{o*}\bar{D}^{o*}$, respectively.

TABLE CAPTIONS

Table 1: Ratios of production cross sections at $\sqrt{s} = 4.028$ GeV. Masses are given in (4.1) and (4.2).

	Case A	Case B
$\sigma(D^{+}D^{-})$	0.36	0.31
$\sigma(D^{o}\bar{D}^{o})$	0.39	0.34
$\sigma(D^{+}D^{-*}) + \sigma(D^{+*}D^{-})$	0.89	0.77
$\sigma(D^{o}\bar{D}^{o*}) + \sigma(D^{o*}\bar{D}^{o})$	1	1
$\sigma(D^{+*}D^{-*})$	0.016	0.014
$\sigma(D^{o*}\bar{D}^{o*})$	0.11	0.26

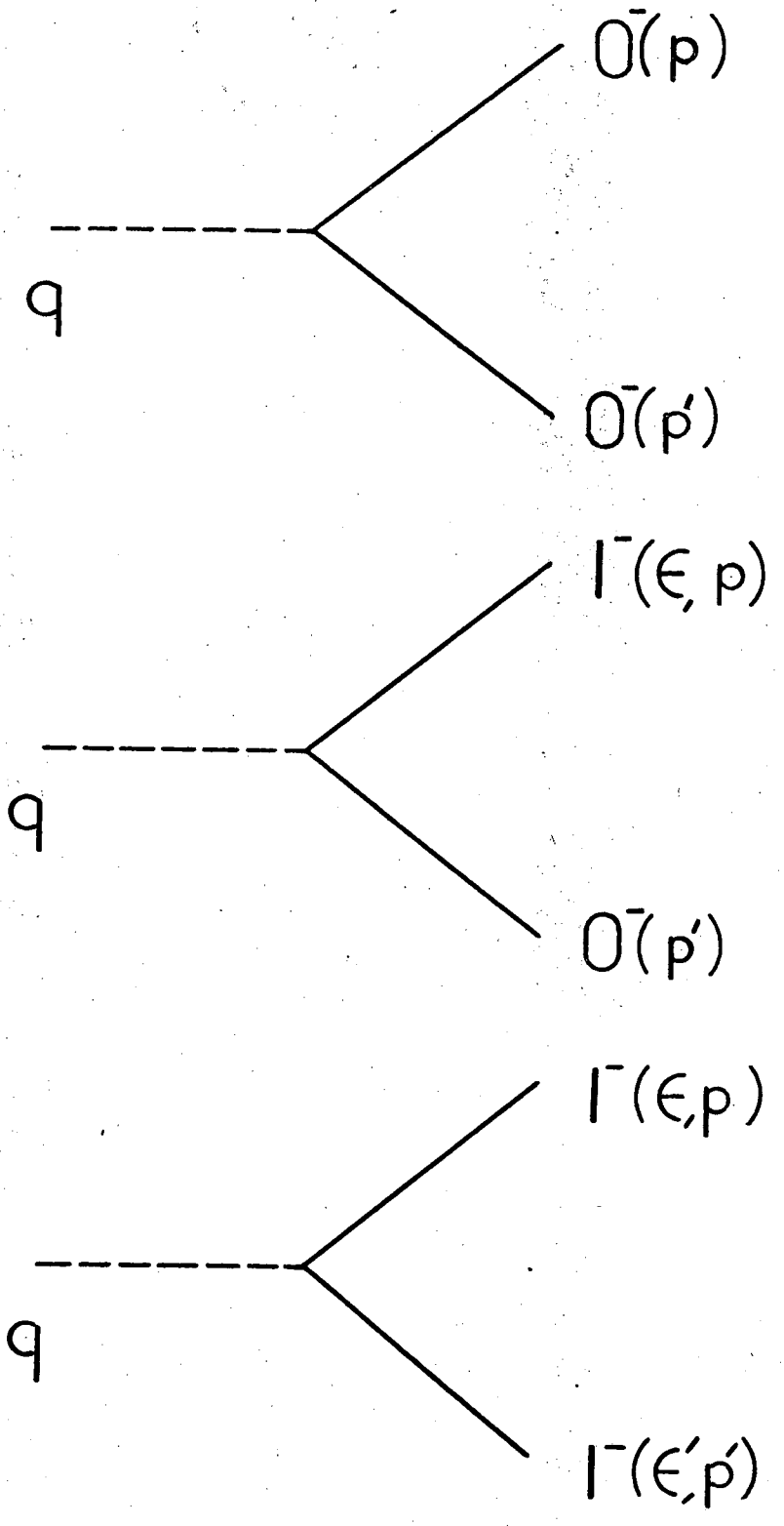

Figure 1

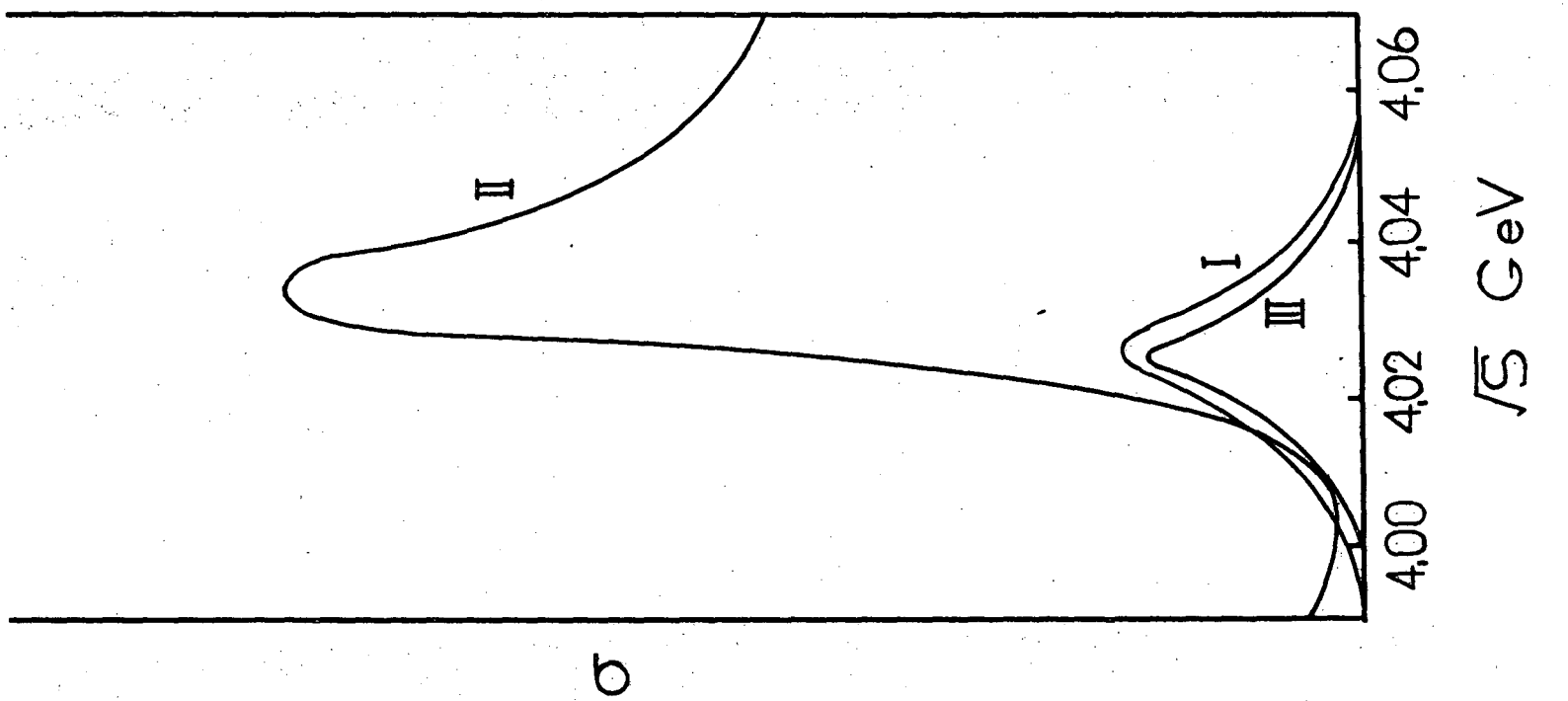

Figure 2(a)

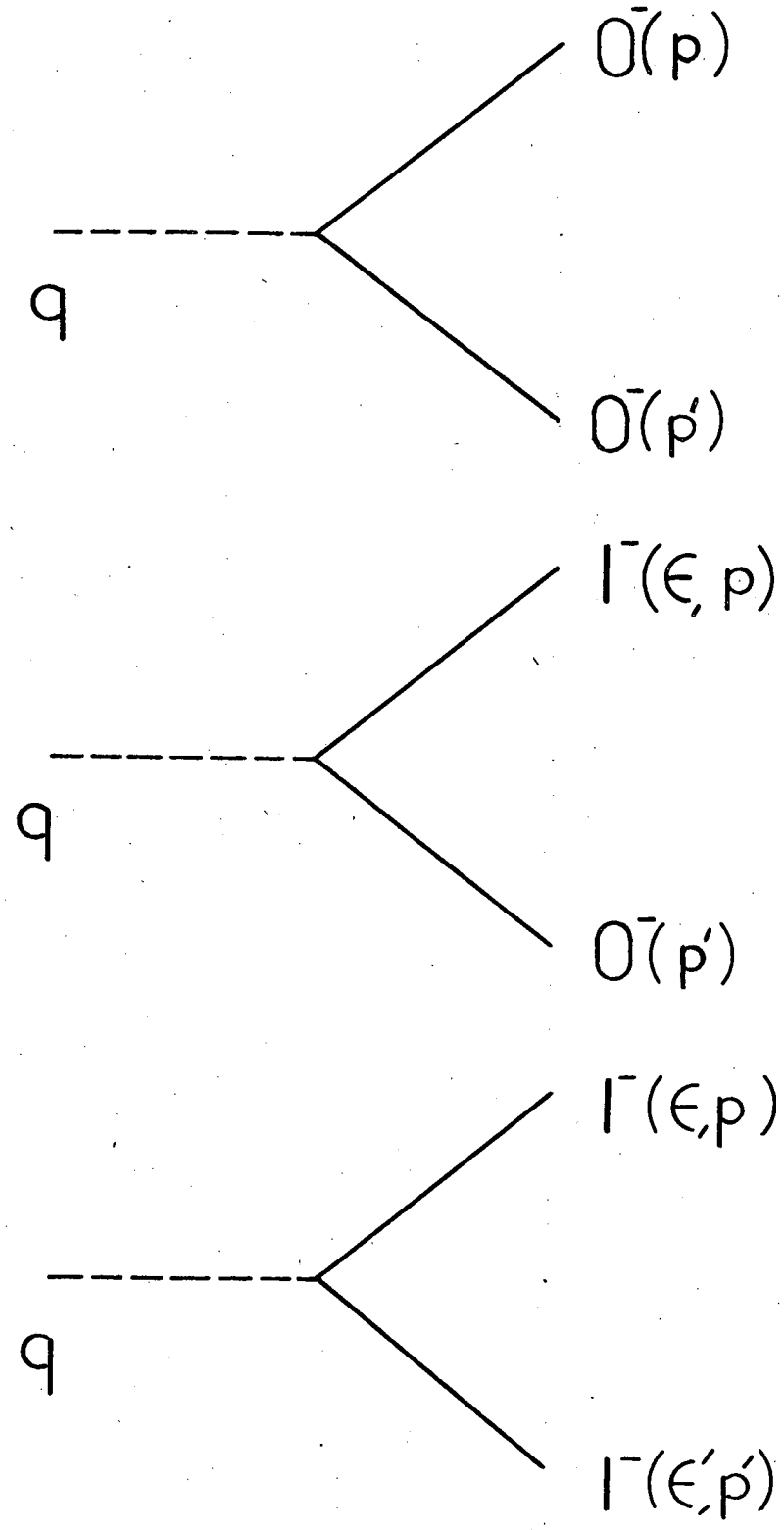

Figure 1

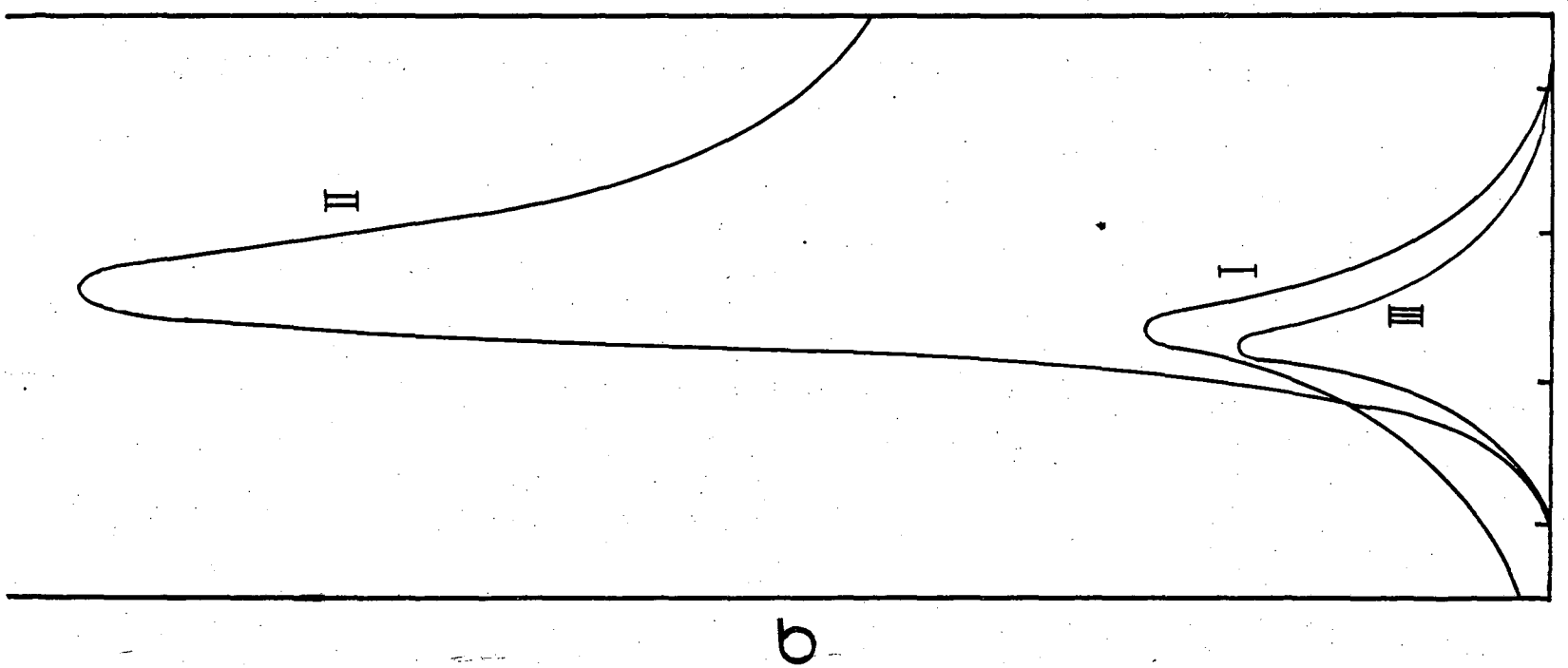

Figure 2(b)

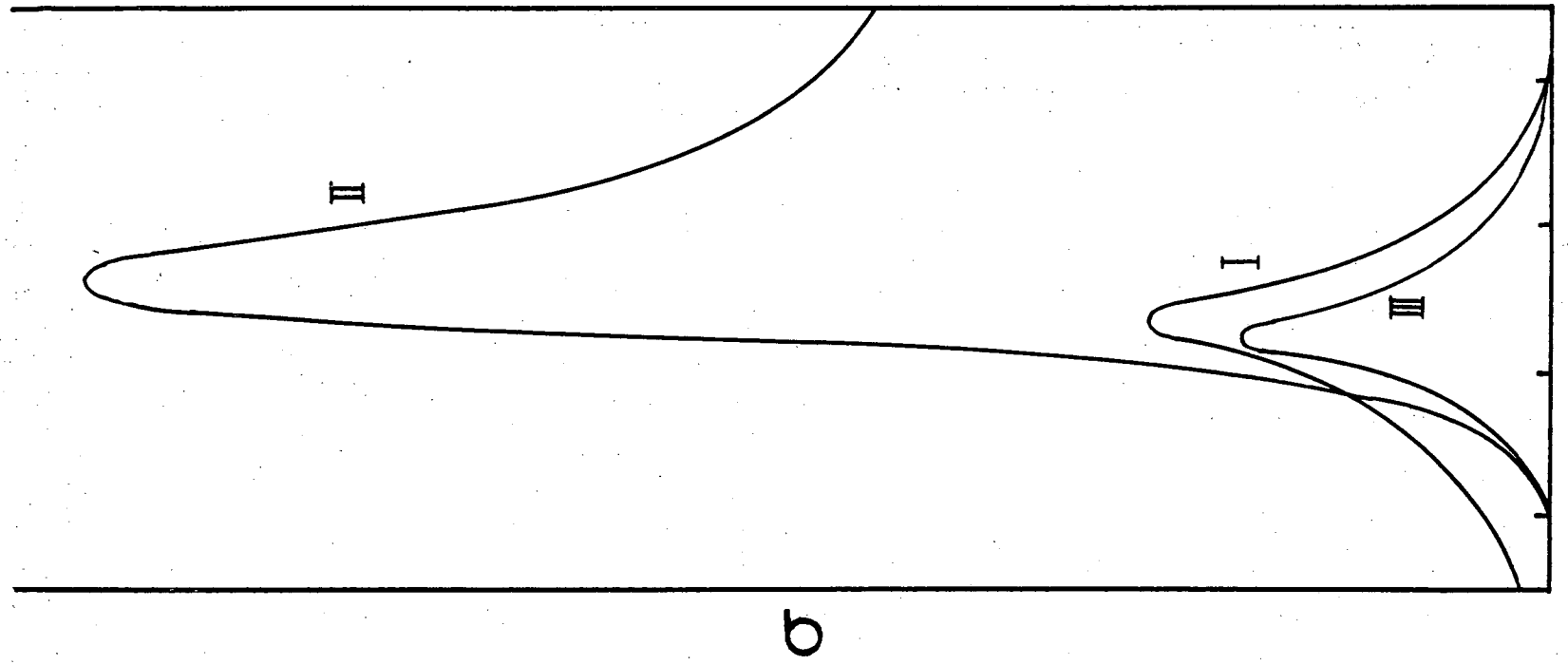

Figure 2(b)

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