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The Decay $\chi(3.45) \to \pi^+\pi^- X(2.83)$: a Test of $c\bar{c}$ Dynamics

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Abstract

We propose to study the decay $\psi' \to \gamma\, \pi^+ \pi^- X(2.83)$ for a better understanding of the nature of the $\chi(3.45)$ and $X(2.83)$ states and as a crucial test of current ideas on $c\bar{c}$ dynamics. Estimates are given for the rates, and possible backgrounds are also discussed.

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Abstract

We propose to study the decay $\psi' \to \gamma\, \pi^+ \pi^- X(2.83)$ for a better understanding of the nature of the $\chi(3.45)$ and $X(2.83)$ states and as a crucial test of current ideas on $c\bar{c}$ dynamics. Estimates are given for the rates, and possible backgrounds are also discussed.

The X(2.83) and $\chi(3.45)$ states are experimentally well established,[1,2] and should be most welcome as the pseudoscalar states in the $c\bar{c}$ system. However, for the charmonium picture [3,4,5], i.e. the nonrelativistic perturbative treatment of QCD, there are serious difficulties [6] with the assignments $X(2.83) \to \eta_c$, $\chi(3.45) \to \eta_c'$ because the comparison of the experiments [1,2,7] with the theoretical estimates [3,4,5] leads to the inequalities

$$\frac{B(X \to \gamma\gamma)}{B(\eta_c \to \gamma\gamma)} = \frac{>(0.6 \pm 0.3) \times 10^{-2}}{\sim 1.2 \times 10^{-3}} > 5 \pm 2.5 \,, \tag{1}$$

$$\frac{B(\chi \to \gamma\, J/\psi)}{B(\eta_c' \to \gamma\, J/\psi)} = \frac{\geq 0.14}{< 10^{-2}} > 10 \,, \tag{2a}$$

$$\frac{\Gamma(J/\psi \to \gamma\, X)}{\Gamma(J/\psi \to \gamma\, \eta_c)} = \frac{<0.02 \times (69 \pm 15)\ \text{keV}}{\sim 20\ \text{keV}} < 0.1 \,, \tag{2b}$$

$$\frac{\Gamma(\psi' \to \gamma\, \chi)}{\Gamma(\psi' \to \gamma\, \eta_c')} = \frac{<0.029 \times (228 \pm 56)\ \text{keV}}{\sim 18\ \text{keV}} < 0.5 \,. \tag{2c}$$

The discrepancies in the branching ratios arise both from the QCD predictions of the hadronic widths in charmonium[3)]

$$\frac{\Gamma(^1S_o \to \text{direct hadrons})}{\Gamma(^3S_1 \to \text{direct hadrons})} \simeq \frac{27}{5}\,\frac{\pi}{\alpha_s(\pi^2 - 9)} \approx 100 \,, \tag{3}$$

and the nonrelativistic selection rules for M1 transitions.[6)]

In order to make a clear cut test of the predictions for the total hadronic widths alone, we suggest to study the reaction

$$\psi' \to \gamma\, \chi(3.45) \to \gamma\, \pi^+ \pi^-\, X(2.83) \to \gamma\, \pi^+ \pi^-\, \gamma\, \gamma \tag{4}$$

which is shown in Fig. 1.

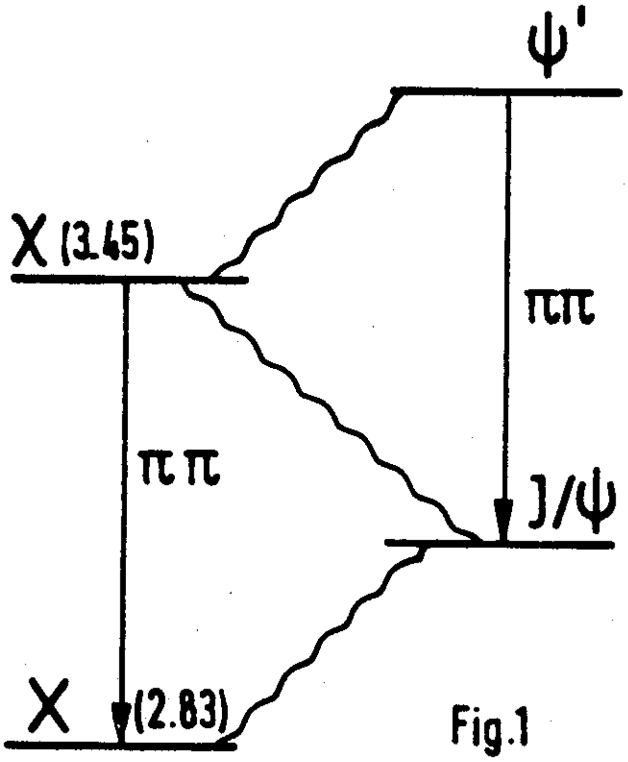

Fig.1

In the conventional QCD picture the branching ratio $B(\eta_c' \to \pi\pi\eta_c)$ should be of the order

$$B(\eta_c' \to \pi\pi\eta_c) \approx \frac{\Gamma(\psi' \to \pi\pi J/\psi)}{100\ \Gamma(\psi' \to \text{direct hadrons}) + \Gamma(\eta_c' \to \gamma J/\psi)} < (3-5)\times 10^{-2} \qquad (5)$$

where the inequality comes from the presence of the important decay mode $\chi(3.45) \to \gamma\ J/\psi$.

From experiments we have:[2,7]

$$\begin{aligned} &B(\psi' \to \chi(3.45)\gamma)\ B(\chi(3.45) \to \gamma\ J/\psi) = (.8 \pm .4) \times 10^{-2}, \\ &B(\psi' \to \chi(3.45)\gamma)\ B(\chi(3.45) \to \gamma\gamma) < 3.1 \times 10^{-4}, \qquad (6) \\ &B(\psi' \to \chi(3.45)\gamma) < 2.9 \times 10^{-2} \end{aligned}$$

whence

$$\begin{aligned} B(\chi(3.45) &\to \gamma\, J/\psi) \geq .27 \pm .13\,, \\ B(\chi(3.45) &\to \gamma\gamma) < .07\,. \end{aligned} \tag{7}$$

Therefore the missing decays of $\chi(3.45)$ are of the order of 50 %, and no direct decays into hadrons have been observed so far.

Any sizeable observation of the process (4) would, because of (5), definitively rule out the charmonium picture. On the other hand, a closer similarity between the $\chi(3.45)$ and the ψ' states will suggest an important branching fraction for the $\chi \to \pi\, \pi\, X$ decay mode, which could almost saturate the missing χ decays.

The observation of a direct transition $\chi \to \pi\, \pi\, X$ would indicate a close relation between these two states and would give strong support to the $c\bar{c}$ nature of the $X(2.83)$ due to the important $\chi \to \gamma\, J/\psi$ decay, in spite of the fact it contradicts the special charmonium dynamics.

An estimate of the rate of the process (4) is easily obtained: assuming a branching ratio $B(\chi{\to}\pi\pi X)$ of 50 % and $B(\psi'{\to}\gamma\chi) \simeq 2$ % (see eqs. (6,7))one gets

$$\begin{aligned} B(\psi' \to \gamma\,\chi \to \gamma\,\pi^+\,\pi^-\,X \to \gamma\,\pi^+\,\pi^-\,\gamma\,\gamma) &\approx 0.66 \times 10^{-2}\, B(X \to \gamma\,\gamma) \\ &\gtrsim (0.4 \pm 0.2) \times 10^{-4} \end{aligned} \tag{8a}$$

where the last inequality comes from eq. (1). This estimate is directly related to the observed rate[1] for $J/\psi \to \gamma\, X \to \gamma\,\gamma\,\gamma \simeq (1.2 \pm 0.5) \times 10^{-4}$ and to the upper limit[7] for $J/\chi \to \gamma\, X$ (eq. (2b)), and therefore it can easily become larger. In fact, the branching ratio $B(X{\to}\gamma\gamma)$ could be of the order of (5-10) %, as one would have guessed for a second order electromagnetic decay, from $B(J/\psi \to e^+\,e^-) \simeq 7$ %. Also from the estimate of $\Gamma(J/\psi \to \eta_c\,\gamma) \simeq 0.5$ keV [8] and the measured value of $B(J/\psi \to X\,\gamma)\, B(X \to \gamma\,\gamma)$ one would get $B(X \to \gamma\,\gamma) \simeq 2$ % and therefore the estimate (8a) is modified

$$B(\psi' \to \gamma\,\pi^+\,\pi^-\,\gamma\,\gamma) \simeq 1.2 \times 10^{-4}\,. \tag{8b}$$

Of course these estimates rely on the assumed branching fraction of $\chi \to \pi\,\pi\,X$ and could therefore be too optimistic. However, the background for the process

(4), as discussed below, is at the same level as eq. (8a), so a sizeable decay should be easily observable.

As far as the $\pi^+\pi^-$ mass spectrum is concerned, the theoretical understanding[9] of the decay $\psi' \to \pi^+\pi^- J/\psi$ [10] in terms of an almost pure S-wave, together with the fact that $m_{\psi'} - m_{J/\psi} \simeq m_{\chi} - m_X$, imply a complete similarity of the $\pi^+\pi^-$ spectrum expected for $\chi \to \pi^+\pi^- X$ with that observed in $\psi' \to \pi^+\pi^- J/\psi$, as well as the absolute values for the partial widths.

From the above results (eqs.(8a-b)) it is crucial to have a clear understanding of all possible backgrounds. The first competitive process which is kinematically almost coincident with (4) (see Fig. 1) is given by

$$\psi' \to \pi^+\pi^- J/\psi \to \pi^+\pi^- \gamma X \to \gamma \pi^+\pi^- \gamma\gamma \tag{9}$$

which occurs at a rate of $(0.4 \pm 0.17) \times 10^{-4}$. Any significant departure from this expected background would then be a clear evidence for the process (4) at a large level.

Other possible reactions which could lead to the same final state $\gamma \pi^+\pi^- X$ are those shown in Fig. 2, i. e.

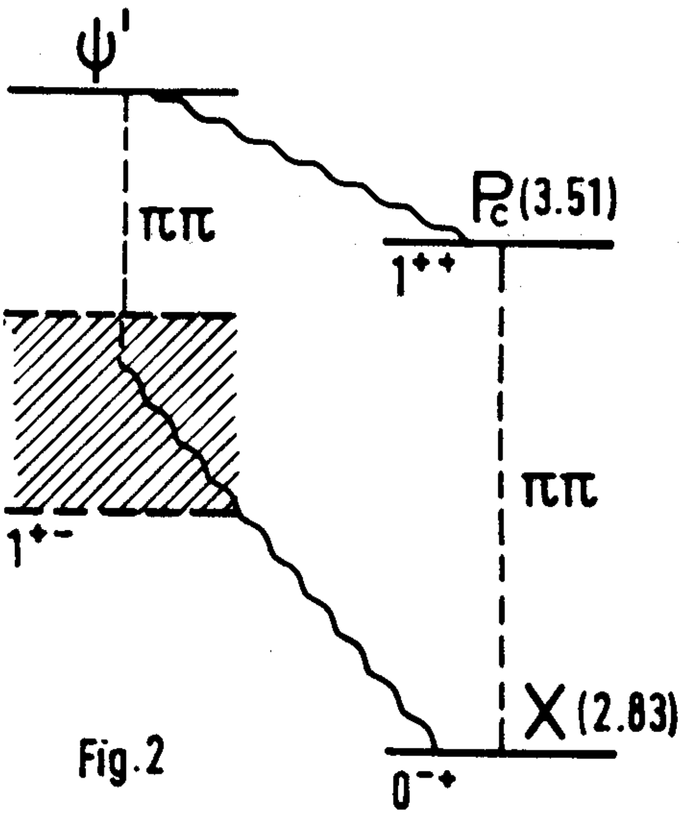

Fig.2

$$\psi' \rightarrow \gamma\, P_c(3.51) \rightarrow \gamma\, \pi^+ \pi^- X$$

and

$$\psi' \rightarrow \pi^+ \pi^-\, {}^1P_1 \rightarrow \pi^+ \pi^- \gamma\, X$$

where the last reaction can occur only if $m({}^1P_1) < m(\psi') - 2\, m_\pi \simeq 3.4$ GeV. However, this background is kinematically distinguishable due to the fact that the $\pi^+\pi^-$ system has to occur in a P-wave, and also for the difference in the γ spectrum. Of course the observation of the latter reaction could be particularly interesting for the establishment of the ${}^1P_1$ state.

Finally, the process $\psi' \rightarrow \omega\, X \rightarrow \pi^+ \pi^- \pi^0\, X$ could occur at the same level as $\psi' \rightarrow \pi^+ \pi^- \gamma\, X$ and therefore a kinematical separation of π^0 and γ is necessary. Needless to say that all these "backgrounds" have their own interest and therefore experimental efforts in this direction are highly desirable.

To summarize we have suggested the decay $\chi(3.45) \rightarrow \pi^+ \pi^- X(2.83)$ as a key for understanding the nature of these two states and the $c\bar{c}$ dynamics.

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