Possible explanation of a broad 1^{--} resonant structure around 1.5 GeV

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The broad 1^{--} resonant structure around 1.5 GeV observed in the K^+K^- mass spectrum in $J/\psi \to K^+K^-\pi^0$ by BESII is interpreted as a composition of $\rho(1450)$ and $\rho(1700)$. A much larger $BR(J/\psi \to \rho(1450, 1700)\pi^0, \rho(1450, 1700) \to \pi^+\pi^-)$ is predicted. Various other tests are proposed.

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Recently, BESII has reported an observation of a broad resonant structure around 1.5 GeV in the K^+K^- mass spectrum in $J/\psi \to K^+K^-\pi^0$ [1]. The quantum numbers of this structure are determined to be 1^{--}. In Ref. [1] a single pole is used to fit the data

$$m = 1576^{+49+98}_{-55-91}\ \text{MeV}, \qquad \Gamma = 818^{+22+64}_{-23-133}\ \text{MeV}. \tag{1}$$

The branching ratio is determined to be

$$B(J/\psi \to X\pi^0)B(X \to K^+K^-) = (8.5 \pm 0.6^{+2.7}_{-3.6}) \times 10^{-4}. \tag{2}$$

Interpretation of this broad structure is a challenge. In Ref. [2] this structure is interpreted as a $K^*(892)$-κ molecule. A tetraquark state [3] and a diquark-antidiquark [4] are proposed to explain the broad width of this structure. It is pointed out in Ref. [5] that two broad overlapped resonances $\rho(1450)$ and $\rho(1700)$ are right at the region of the broad structure and have the same quantum numbers. The final state interactions of $\rho(1450, 1700) \to K^+K^-$ are studied in Ref. [5] and the $B(J/\psi \to \pi^0\rho(1450, 1700))B(\rho(1450, 1700) \to K^+K^-) \sim 10^{-7}$ is obtained. This branching ratio is far less than the experimental value (2).

In the range of $\rho(1600)$ there is complicated structure. A lot of strong evidence shows that the 1600-MeV region actually contains two ρ-like resonances: $\rho(1450)$ and $\rho(1700)$ [6]. In this paper the possibility that the broad structure mentioned above is caused by $\rho(1450)$ and $\rho(1700)$ is revisited. The arguments are the following:

(1) Their quantum numbers are 1^{--}, which are the same as the ones of the structure. They are isovectors and can be produced in $J/\psi \to \rho(1450, 1700)\pi$.

(2) Their masses are in the region of the structure.

(3) The decay mode of $\rho(1450, 1700) \to K\bar{K}$ has been found [7]. Therefore, these two resonances do contribute to $J/\psi \to K\bar{K}\pi$.

(4) Can the contributions of $\rho(1450, 1700)$ explain the $BR(J/\psi \to X\pi^0)B(X \to K^+K^-)$ (2)? This is a very important issue. In Ref. [5] loop diagrams are calculated to determine the decay rates of $\rho(1450, 1700) \to K\bar{K})$. Very small branching ratios are found, and the authors conclude that comparing with the data (2), $BR(J/\psi \to \rho(1450, 1700)\pi^0 \to K^+K^-\pi^0)$ is too small. A different point of view is presented in this paper. The $\rho(770)$ meson is an isovector and made of u and d quarks. In a chiral field theory of pseudoscalar, vector, and axial vector mesons [8] it is shown that $\rho(770)$ is coupled to $K\bar{K}$ at the tree level [8]:

$$\begin{aligned}
\mathcal{L}_{\rho K\bar{K}} &= \frac{2}{g} f_\rho(q^2) f_{iab}\rho^i_\mu K_a \partial_\mu K_b,\\
\mathcal{L}_{\rho\pi\pi} &= \frac{2}{g} f_\rho(q^2) \epsilon_{ijk}\rho^i_\mu \pi^j \partial_\mu \pi^k,\\
f_\rho(q^2) &= 1 + \frac{q^2}{2\pi^2 m_\rho^2}\left\{\left(1 - \frac{2c}{g}\right)^2 - 4\pi^2c^2\right\},\\
c &= \frac{f_\pi^2}{2gm_\rho^2},
\end{aligned} \tag{3}$$

where g is a universal coupling constant and determined to be 0.39 and q is the momentum of the ρ meson. Equations (3) show that in the chiral limit the strengths of the couplings $\rho\pi\pi$ and $\rho K\bar{K}$ are the same at the tree level. In this chiral theory the ω meson couples to $K\bar{K}$ at the tree level too. All $\rho K\bar{K}$, $\omega K\bar{K}$, and $\phi K\bar{K}$ couplings (the strengths of all these three couplings are the same at the tree level) contribute to both the form factors of the charged kaon and neutral kaon [9]. Theory agrees with the data very well. The decay $\tau \to K\bar{K}\nu$ is dominated by the vertex $\mathcal{L}_{\rho K\bar{K}}$ at the tree level. Theory is in good agreement with the data [10]. The vertex $\mathcal{L}_{\rho K\bar{K}}$ at the tree level contributes to πK scatterings, too [11], and good agreement with data is obtained [11]. Therefore, the coupling $\rho K\bar{K}$ at the tree level exists and is supported by experiments. In this chiral field theory meson vertices at the tree level are at the leading order in N_C expansion, and loop diagrams of mesons are at higher order. Therefore, loop diagrams of mesons are suppressed in N_C expansion. For example, $m_\omega - m_\rho$, $m_{f_1(1285)} - m_{a_1}$, $BR(\phi \to \rho\pi)$ are from one-loop diagrams of mesons, and they are small. Comparing with $\rho(770)$, $\rho(1450, 1700)$ are isovectors too. There is no obvious reason why the couplings $\rho(1450, 1700)K\bar{K}$ at the tree level are forbidden. On the other hand, based on the arguments of Ref. [8], loop diagrams of mesons are at higher order in N_C expansion. Therefore, $BR(\rho(1450, 1700) \to K\bar{K})$ obtained from loop diagrams of mesons in Ref. [5] are small. Adding tree diagrams at the leading order in N_C expansion, the increase of $BR(\rho(1450, 1700) \to K\bar{K})$ should be expected.

(5) As a matter of fact, in the first item of Ref. [12], the total widths of $\rho(1450, 1700)$ and the partial widths of $\pi\pi$ and $K\bar{K}$ decay modes have been predicted by a successful 3P0 model (see Tables V, VIII, XV of the first item of [12]):

$$B(\rho(1465) \to \pi\pi) = 0.27,$$
$$B(\rho(1465) \to K\bar{K}) = 0.063,$$
$$B(\rho(1700) \to \pi\pi) = 0.11,$$
$$B(\rho(1700) \to K\bar{K}) = 0.041.$$

These results show that $B(\rho(1465, 1700) \to K\bar{K}$ are much larger than 1.6×10^{-3} [7] which is used in Ref. [1,5].

(6) As mentioned above, $BR(\rho(1450) \to K\bar{K})$ is an important issue in establishing the contributions of $\rho(1450, 1700)$ to $J/\psi \to K^+K^-\pi^0$. In Ref. [7] $BR(\rho(1450) \to K\bar{K}) < 1.6 \times 10^{-3}$ is listed. This value has been quoted in Refs. [1,5]. Especially, the possibility that the broad X were from $\rho(1450)$ has been ruled out in Ref. [1] because "the $\rho(1450)$ is known to have a very small branching fraction to K^+K^- ($< 1.6 \times 10^{-3}$ at 95% C.L.) ... We would have $BR[J/\psi \to \rho(1450)\pi^0]BR[\rho(1450) \to K^+K^-] = (5.0 \pm 0.4) \times 10^{-4}$."
However, based on the data listed in Ref. [7] there are other different possible estimates of $BR(\rho(1450) \to K^+K^-)$.

(a) $\frac{\Gamma(K\bar{K})}{\Gamma(\omega\pi)} < 0.08$ and $\frac{\Gamma(\omega\pi)}{\Gamma_{\text{total}}} \sim 0.21$ are presented in Ref. [7], too. They are quoted from Ref. [13,14]. These two values lead to $BR(\rho(1450) \to K\bar{K}) < 1.68 \times 10^{-2}$. This upper limit is higher by 1 order of magnitude than the one listed in Ref. [7].

(b) In Ref. [13] $\sigma(e^+e^- \to \rho(1450) \to K\bar{K}) < 1nb$ and $\sigma(e^+e^- \to \rho(1450) \to \omega\pi) \sim 12.5$ nb are determined. $\frac{\Gamma(K\bar{K})}{\Gamma(\omega\pi)} < 0.08$ is obtained. $\Gamma(\rho(1450)) = 0.311 \pm 0.062$ GeV and $\Gamma(\rho(1450) \to \omega\pi) \sim$ 52–78 MeV have been reported in Ref. [14]. $\frac{\Gamma_{\omega\pi}}{\Gamma_{\text{tot}}} < (0.167 - 0.25)(1 \pm 0.2)$ and $\Gamma_{K\bar{K}}/\Gamma_{\text{tot}} < 1.34 \times 10^{-2}$ are estimated.

(c) The experimental data of $BR(\rho(1700) \to \pi^+\pi^-)$ are presented in Ref. [7]: $0.287^{+0.043}_{-0.02}$, $0.15 - 0.30$, <0.2, 0.30 ± 0.05, <0.15, 0.25 ± 0.05. It is similar to Eqs. (3) that in the chiral limit, $m_q \to 0$, the following effective Lagrangians are constructed:

$$\mathcal{L}_{\rho K\bar{K}} = g_\rho f_{iab} \rho^i_\mu K_a \partial_\mu K_b, \qquad \mathcal{L}_{\rho\pi\pi} = g_\rho \epsilon_{ijk} \rho^i_\mu \pi^j \partial_\mu \pi^k, \tag{4}$$

where $g_{\rho(1450)}$ and $g_{\rho(1700)}$ are different. The decay widths are derived:

$$\Gamma(\rho^0 \to \pi^+\pi^-) = \frac{g_\rho^2}{48\pi} m_\rho \left(1 - \frac{4m_\pi^2}{m_\rho^2}\right)^{3/2}, \qquad \Gamma(\rho^0 \to K\bar{K}) = \frac{g_\rho^2}{96\pi} m_\rho \left(1 - \frac{4m_K^2}{m_\rho^2}\right)^{3/2}, \tag{5}$$

where ρ is $\rho(1450)$ and $\rho(1700)$, respectively. If $BR(\rho(1700) \to \pi^+\pi^-) \sim 0.2$, $BR(\rho(1700) \to K\bar{K}) \sim 5.6 \times 10^{-2}$ is obtained from Eq. (5). In this effective theory $g_{\rho(1450),\rho(1700)}$ cannot be predicted and they are taken as two parameters. However, the chiral symmetry predicts that the same parameter appears in both decay modes (4) and (5). Therefore, the data of the branching ratio of the $\pi\pi$ mode can be used to predict the branching ratio of the $K\bar{K}$ mode. If $BR(\rho(1700) \to \pi^+\pi^-) < 0.15$, $BR(\rho(1700) \to K\bar{K}) < 4.2 \times 10^{-2}$ is obtained. For $\rho(1450)$,$BR(\rho(1450) \to \omega\pi) \sim 0.21$ and $\frac{\Gamma(\pi\pi)}{\Gamma(\omega\pi)} \sim 0.32$ are listed in Ref. [7]. $BR(\rho(1450) \to K\bar{K}) \sim 1.37 \times 10^{-2}$ is obtained.

(d) $\rho(1450, 1700) \to K^+K^-$ are found in $\bar{p}p \to \rho(1450, 1700) \to K^+K^-\pi^0$ [15], and $B(\bar{p}p \to \rho(1450)\pi \to K^+K^-\pi^0) = (3.5 \pm 0.7) \times 10^{-4}$ and $B(\bar{p}p \to \rho(1700)\pi \to K^+K^-\pi^0) = (2.9 \pm 0.8) \times 10^{-4}$ are reported [15]. In Ref. [16] $BR(\bar{p}d \to \pi^-\pi^-\pi^+ p_{\text{spectator}}) = (1.1 \pm 0.1) \times 10^{-2}$ is presented. $\rho(770)$, $\rho(1450)$, $\rho(1700)$, $f_2(1275)$... are found in this process. From the data [15,16],

$$\frac{BR(\rho(1450) \to K\bar{K})}{BR(\rho(1450) \to \pi\pi)} > 3.18(1 \pm 0.29) \times 10^{-2}, \qquad \frac{BR(\rho(1700) \to K\bar{K})}{BR(\rho(1700) \to \pi\pi)} > 2.6(1 \pm 0.37) \times 10^{-2} \tag{6}$$

are estimated. Using the branching ratios of the $\pi\pi$ channel estimated above, the estimations of the $K\bar{K}$ channel are obtained:

$$BR(\rho(1450)\to K\bar{K}) > 1.96(1\pm 0.29)\times 10^{-3},$$
$$BR(\rho(1700)\to K\bar{K}) > 5.2(1\pm 0.37)\times 10^{-3}. \qquad (7)$$

In Eq. (7) $BR(\rho(1700)\to \pi\pi)\sim 0.2$ is used. It is necessary to point out that it is assumed that the K^+K^- states reported in Refs. [15,16] are due to the $\rho(1450)$ and $\rho(1700)$ but in fact their isospin is not determined, so they could be due to the $\omega(1420)$ and $\omega(1650)$, or indeed to some mixture of both isospin states. This problem is stressed by the Particle Data Group [7]. The data of Refs. [15,16] are used to estimate the order of magnitudes of $BR(\rho(1450, 1700)\to K\bar{K})$. Taking $\omega(1420, 1650)$ into account, if the interferences between $\rho(1450, 1700)$ and $\omega(1420, 1650)$ are constructive the values of Eq. (6) are decreased, and if the interferences are destructive the values of Eq. (6) are increased.

It must be stressed that it is not the purpose of this paper to present a more accurate $BR(\rho(1450, 1700)\to K\bar{K})$. As pointed out by Eidelman [17], "The heart of the problem is in the internal inconsistency of the data listed in this section" of Ref. [7]. The purpose of the discussion of the $BR(\rho(1450, 1700)\to K\bar{K})$ is to show that there is an inconsistency in determining $BR(\rho(1450, 1700)\to K\bar{K})$. The only thing known is that $BR(\rho(1450, 1700)\to K\bar{K})$ are nonzero. Therefore, using $BR(\rho(1450, 1700)\to K\bar{K})$ to rule out $\rho(1450, 1700)$ is not reliable.

(7) The experimental values of the widths of $\rho(1450, 1700)$ have a wide range [7]. The range of the width of $\rho(1450)$ is 60–547 $\pm\, 86^{+46}_{-45}$ MeV [7] and for $\rho(1700)$ it is 100–850 $\pm$ 200 MeV [7]. In a high statistics study of the decay $\tau^-\to\pi^-\pi^0\nu_\tau$ [18], both $\rho(1450, 1700)$ are found. In one fit, $\Gamma(\rho(1450)) = 471\pm 29\pm 21$ MeV and $\Gamma(\rho(1700)) = 255\pm 19\pm 79$ MeV are determined. $\Gamma(\rho(1450)) = 553\pm 31\pm 21$ MeV and $\Gamma(\rho(1700)) = 567\pm 81\pm 79$ MeV are obtained in the second fit. Therefore, it is not a problem to use $\rho(1450, 1700)$ to understand the broad structure (1).

Therefore, the study presented above shows that the branching ratio of $\rho(1450, 1700)\to K\bar{K}$ is much larger than 1.6×10^{-3}. If the larger branching ratio of $\rho(1450)\to K^+K^-$ is used in the estimation made in Ref. [1], $BR[J/\psi\to\rho(1450)\pi^0]BR[\rho(1450)\to K^+K^-]$ should be greater than $(5.0\pm 0.4)\times 10^{-4}$ [1] and the experimental value (2) is not a problem for the scheme in which the resonant structure is caused by $\rho(1450, 1700)$. $\rho(1450, 1700)$ cannot be ruled out in understanding the broad structure observed in $J/\psi\to K^+K^-\pi^0$ [1].

An effective Lagrangian for $J/\psi\to\rho(1450, 1700)\pi^0\to K^+K^-\pi^0$ is constructed to calculate the K^+K^- invariant mass distribution:

$$\mathcal{L}_{J/\psi\to\rho\pi} = \frac{2g_J}{f_\pi}\epsilon^{\mu\nu\alpha\beta}(\partial_\mu J_\nu - \partial_\nu J_\mu)(\partial_\alpha\rho^i_\beta - \partial_\beta\rho^i_\alpha)\pi^i, \quad (8)$$

where ρ is either $\rho(1450)$ or $\rho(1700)$. Using Eqs. (4) and (8), the distribution of $J/\psi\to\rho(1450, 1700)\pi^0\to K^+K^-\pi^0$ is obtained:

$$\frac{d\Gamma}{dq^2} = \frac{1}{9f_\pi^2 m_J^4}\frac{1}{(2\pi)^3}(q^2-4m_K^2)^{3/2}\{(m_J^2+q^2-m_{\pi^0}^2)^2 - 4m_J^2q^2\}^{3/2} \times\sum_i\left|\frac{g_1}{q^2-m_1^2+i\sqrt{q^2}\Gamma_1}+\frac{g_2}{q^2-m_2^2+i\sqrt{q^2}\Gamma_2}\right|^2, \quad (9)$$

where q is the momentum of ρ and $g_{1,2}$ are two coupling constants.

In Ref. [1] there are two sets of data. The mass and the width of the resonance are shown in Eq. (1). In Fig. 1c of Ref. [1] the K^+K^- invariant mass distribution is presented. Equation (9) is used to fit these data. The distribution shown in Fig. 1 is the fit of the mass and the width of the resonance (1). The parameters are chosen to be $\Gamma_1 = 0.65$ GeV, $\Gamma_2 = 0.45$ GeV, $g_1 = 11.8g_2$, $m_1 = 1.42$ GeV, and $m_2 = 1.7$ GeV. Figure 1 shows that the peak is at 1.54 GeV which is within the range of the mass of the structure observed by BESII(1), and the width is about 720 MeV which is still in the range of the experimental value (1) 683–886 MeV. Figure 1 shows $\rho(1450)$ plays a dominant role in the decay $J/\psi\to K^+K^-\pi^0$. However, $\rho(1700)$ makes the distribution wider. Figure 1 shows that the mass and the width of the structure observed in $J/\psi\to K^+K^-\pi^0$ (1) can be qualitatively understood by the processes $J/\psi\to\rho(1450, 1700)\pi^0$.

The fit of the K^+K^- invariant mass distribution (Fig. 1c of Ref. [1]) is shown in Fig. 2. The parameters are chosen to be $\Gamma_1 = 0.65$ GeV, $\Gamma_2 = 0.45$ GeV, $g_1 = -7.92g_2$, $m_1 = 1.3$ GeV, and $m_2 = 1.6$ GeV. Under the values of these parameters Eq. (9) fits the data pretty well (Fig. 2). It is

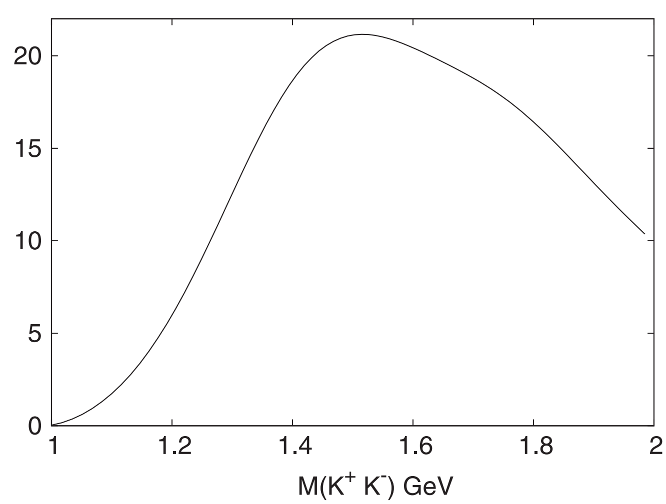

FIG. 1. Distribution of the invariant mass of K^+K^- of $J/\psi\to K^+K^-\pi^0$ with arbitrary units.

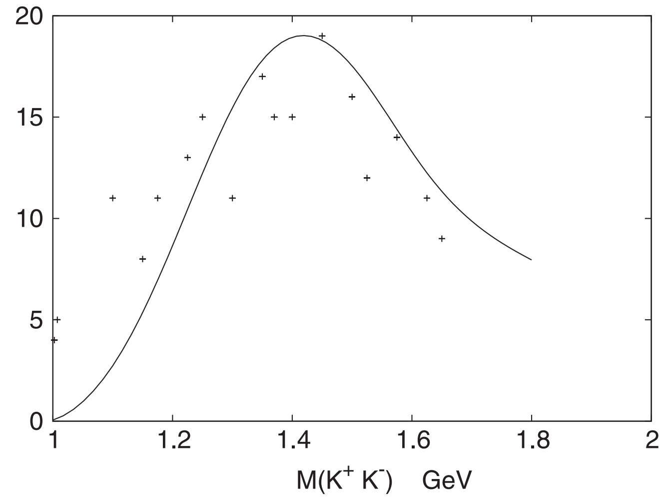

FIG. 2. Distribution of the invariant mass of K^+K^- of $J/\psi \to K^+K^-\pi^0$ with arbitrary units. The dots are drawn from the histogram of Fig. 1c of Ref. [1].

similar to the fit shown in Fig. 1 in that $\rho(1450)$ plays a dominant role in the decay $J/\psi \to K^+K^-\pi^0$ and $\rho(1700)$ makes the distribution wider. The masses of $\rho(1450, 1700)$ determined in this fit are lower than the masses 1450 GeV and 1700 GeV, respectively. These two $\rho's$ are wide resonances. There are uncertainties in determining the masses of wide resonances. In Ref. [7] the lower masses(GeV) 1250, 1290 ± 40, 1282 ± 37, 1292 ± 17, 1265.5 ± 75.3 for $\rho(1450)$ and 1546 ± 20, 1550 ± 70, 1570 ± 60, 1550 ± 60, 1550 ± 50, 1450 ± 100, 1430 ± 50 ... for $\rho(1700)$ are listed.

The masses of two $\rho's$ determined in the second fit are lower than the ones of fit 1. In the second fit g_2 is smaller but negative. Large experimental errors are one of the two causes of the differences. The second cause is that Fig. 1c of Ref. [1] is the distribution of events. To obtain $\frac{d\Gamma}{d\sqrt{q^2}}$ the event distribution should be corrected by the number of the events of J/ψ and the efficiency of acceptance. The corrections are not available in Ref. [1].

It should be mentioned that $\omega(1420, 1650)$ are another two 1^{--} candidates for the wide bump observed in the K^+K^- invariant mass distribution in the decay $J/\psi \to K^+K^-\pi^0$. Both J/ψ and ω are isoscalars and π is a isovector. The G parities of J/ψ, ω, π are negative. The decay $J/\psi \to \omega(1420, 1650)\pi^0$ violates the conservations of isospin and G parity. J/ψ can, via $\rho - \omega$ mixing, decay to $\omega(1420, 1650)\pi^0$. $\rho - \omega$ mixing is caused by the mass difference of u and d quarks or by electromagnetic interactions [19]. Of course, the decay $J/\psi \to \omega(1420, 1650)\pi^0$ can proceed directly via the effects of the mass difference of u and d quarks or electromagnetic interactions. $J/\psi \to \omega\pi^0$ is a good example. $BR(J/\psi \to \rho^0\pi^0) = (5.6 \pm 0.7) \times 10^{-3}$ and $BR(J/\psi \to \omega\pi^0) = (4.5 \pm 0.5) \times 10^{-4}$ [7]. Therefore, it is reasonable that $BR(J/\psi \to \omega(1420, 1650)\pi^0, \omega(1420, 1650) \to K^+K^-)$ is much smaller than $BR(J/\psi \to \rho(1450, 1700)\pi^0, \rho(1450, 1700) \to K^+K^-)$. Larger errors are shown in the current data [Eq. (2)]; the small contribution of $\omega(1420, 1650) \to K^+K^-$ to $J/\psi \to K^+K^-\pi^0$ is ignored in this paper.

It is well-known that $\rho(1450, 1700)$ can decay to $\pi^+\pi^-$. Therefore, the prediction is that $\rho(1450, 1700)$ must be found in the $\pi^+\pi^-$ mass spectrum of $J/\psi \to \pi^+\pi^-\pi^0$. One can make a quantitative prediction of $BR(J/\psi \to \rho(1450, 1700)\pi^0, \rho(1450, 1700) \to \pi^+\pi^-)$ and the distribution of the invariant mass of $\pi^+\pi^-$ of this process. Using Eqs. (4) and (8), the distribution of $BR(J/\psi \to \rho(1450, 1700)\pi^0, \rho(1450, 1700) \to \pi^+\pi^-)$ is obtained:

$$\frac{d\Gamma}{dq^2} = \frac{4}{9f_\pi^2 m_J^4}\frac{1}{(2\pi)^3}(q^2 - 4m_\pi^2)^{3/2}\{(m_J^2 + q^2 - m_{\pi^0}^2)^2 - 4m_J^2 q^2\}^{3/2}\sum_i \left|\frac{g_1}{q^2 - m_1^2 + i\sqrt{q^2}\Gamma_1} + \frac{g_2}{q^2 - m_2^2 + i\sqrt{q^2}\Gamma_2}\right|^2. \tag{10}$$

The parameters of Eq. (10) take the values determined in the first fit. It is determined that

$$\begin{aligned} &BR(J/\psi \to \rho^0(1450, 1700)\pi^0 \to \pi^+\pi^-\pi^0) \\ &\quad \sim 11.5BR(J/\psi \to \rho^0(1450, 1700)\pi^0 \to K^+K^-\pi^0) \\ &\quad \sim 11.5 \times (8.5 \pm 0.6^{+2.7}_{-3.6}) \times 10^{-4}. \end{aligned} \tag{11}$$

Equations (9) and (10) are proportional to corresponding decay widths (5) respectively (replacing m_ρ^2 by q^2). The fit shows (Fig. 1) that $\rho(1450)$ dominates the distribution. Therefore, ignoring the contribution of $\rho(1700)$ and the effect of the resonance distribution, the ratio $BR(J/\psi \to \pi^+\pi^-\pi^0)/BR(J/\psi \to K^+K^-\pi^0)$ is proportional to

$$\Gamma(\rho(1450) \to \pi^+\pi^-)/\Gamma(\rho(1450) \to K^+K^-) = 9.4.$$

As presented in (6)(c), the estimation of the order of magnitude of $BR(\rho(1450) \to K\bar{K})$ obtained from $BR(\rho(1450) \to \pi^+\pi^-)$ is consistent with other estimations and the 3P0 model.

The decays of $\rho(1450, 1700)$ have been successfully studied by the 3P0 model [12]. Using $BR(\rho(1465) \to \pi\pi, K^+K^-)$ obtained by the 3P0 model, the estimation in the resonance area is revealed:

$$\begin{aligned} &BR(J/\psi \to \pi^+\pi^-\pi^0) \\ &\quad \sim 8.5BR(J/\psi \to K^+K^-\pi^0) \\ &\quad \sim 8.5 \times (8.5 \pm 0.6^{+2.7}_{-3.6}) \times 10^{-4}. \end{aligned} \tag{12}$$

In the estimation (12) the dominance of $\rho(1450)$ is taken into account. Equation (11) is based on the effective

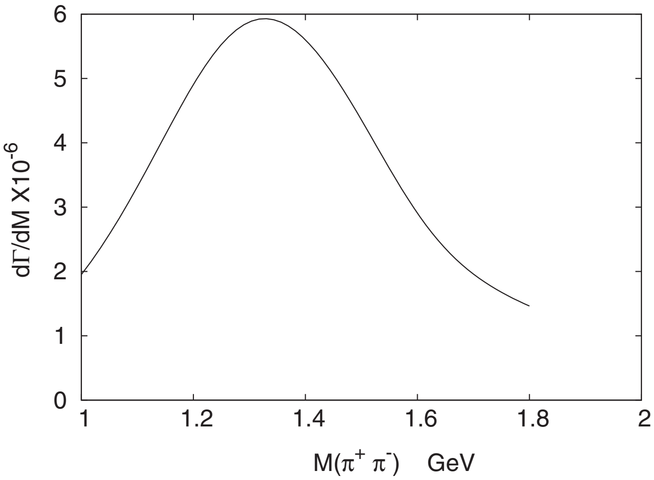

FIG. 3. Distribution $\frac{d\Gamma}{d\sqrt{q^2}}(J/\psi \to \pi^+\pi^-\pi^0)$, $\sqrt{q^2} = M$.

Lagrangian and Eq. (12) is the result of the 3P0 model. These two results are close to each other.

Equation (11) shows that $BR(J/\psi \to \pi^+\pi^-\pi^0)$ is much larger than $BR(J/\psi \to K^+K^-\pi^0)$ in the region of $M(\pi^+\pi^-) \sim 1.5$ GeV. This is the decisive prediction for the scheme of $\rho^0(1450, 1700)$ which are responsible for the decay $J/\psi \to K^+K^-\pi^0$ in the region of $M(K^+K^-)$ around 1.5 GeV. In the resonance area the prediction of the distribution of $BR(J/\psi \to \pi^+\pi^-\pi^0)$ is shown in Fig. 3.

In Ref. [20] the decays $J/\psi \to \pi^+\pi^-\pi^0$ have been studied. The event distributions of the invariant mass of two pions are shown in Fig. 4 of Ref. [20]. However, the indication of the resonant structure predicted in this paper is not shown in the event distributions (Fig. 4 of Ref. [20]). Fig. 4 of Ref. [20] shows that there is a broad enhancement in high-mass regions in the distribution of $J/\psi \to \pi^+\pi^-\pi^0$. It is similar that a broad enhancement in high-mass regions is shown in the distribution of $J/\psi \to K^+K^-\pi^0$ too (Fig. 1c of Ref. [1]). Fig. 1c of Ref. [1] shows that the vector signal in the K^+K^- invariant mass distribution is a small part of the total. Therefore, it is reasonable that the vector resonant structure in the $\pi\pi$ invariant mass distribution is small part of the total too. On the other hand, the Dalitz plot in Fig. 3 of Ref. [20] shows that it is worth a detailed study of the event distributions in the regions 1 GeV$^2 < m^2(\pi^+\pi^0)$, $m^2(\pi^-\pi^0) <$ 2 GeV^2.

$\rho(1450, 1700)$ have other decay modes. The decay mode $\rho(1450, 1700) \to 4\pi$ has been found [7]. $\rho\pi\pi$ is the dominant decay channel of $\rho(1700)$. According to the chiral meson theory [8], a_1 strongly couples to $\rho\pi$. Therefore, $\rho(1700) \to \rho\pi\pi$ is dominated by $\rho(1700) \to a_1\pi$. Because of the small phase space of $\rho(1450) \to a_1(1260)\pi$, $BR(\rho(1450) \to a_1(1260)\pi \to \rho\pi\pi)$ is small. $\rho(1700)$ can be searched in $J/\psi \to \rho(1700)\pi \to a_1\pi\pi$. $\rho(1450, 1700) \to \eta\rho, \omega\pi$ are discovered [7]. $\rho(1450, 1700)$ can be found in $J/\psi \to \rho(1450, 1700)\pi \to \eta\rho\pi, \omega\pi\pi, K^*\bar{K}, \bar{K}^*K$. $\rho(1450, 1700) \to \phi\pi$ are Okubo-Zweig-Iizuka suppressed. Therefore, $BR(\rho(1450, 1700) \to \phi\pi)$ are much smaller than $BR(\rho(1450, 1700) \to \pi\pi, a_1\pi, \eta\pi, \omega\pi)$. However, if the broad structure is a four quark state X [3,4] which decays via "fall apart," there is no suppression for this four quark state to decay to $\phi\pi$. Larger $BR(J/\psi \to X\pi \to \phi\pi\pi)$ and very small $BR(J/\psi \to X\pi \to \pi\pi\pi, a_1\pi\pi, \eta\rho\pi, \omega\pi\pi)$ should be expected if X is a four quark state.

The nature of $\rho(1450, 1700)$ is very interesting. In Ref. [12] the authors claim that $\rho(1450)$ has a mass consistent with radial 2s, but its decays show characteristics of hybrids, and suggest that this state may be a 2s-hybrid mixture. In Ref. [21] it is argued that the inclusion of an isovector hybrid is essential for explaining the $e^+e^- \to 4\pi$ data.

In summary, the broad structure reported by BESII can be understood by $J/\psi \to \rho(1450, 1700)\pi^0 \to K^+K^-\pi^0$. A larger $BR(J/\psi \to \rho^0(1450, 1700)\pi^0 \to \pi^+\pi^-\pi^0)$ is predicted. Searching for $\rho(1450, 1700)$ in $J/\psi \to \pi^+\pi^-\pi^0$ is a serious test for this scheme. Various other tests are presented.

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