

UC Irvine

UC Irvine Previously Published Works

Title

Charmonium Decays to Axial-Vector Plus Pseudoscalar Mesons

Permalink

<https://escholarship.org/uc/item/22b0k377>

Journal

Physical Review Letters, 83(10)

ISSN

0031-9007

Authors

Bai, JZ
Ban, Y
Bian, JG
[et al.](#)

Publication Date

1999-09-06

DOI

10.1103/physrevlett.83.1918

Copyright Information

This work is made available under the terms of a Creative Commons Attribution License, available at <https://creativecommons.org/licenses/by/4.0/>

Peer reviewed

Charmonium Decays to Axial-Vector Plus Pseudoscalar Mesons

J. Z. Bai,¹ Y. Ban,⁵ J. G. Bian,¹ I. Blum,¹² G. P. Chen,¹ H. F. Chen,¹¹ J. Chen,³ J. C. Chen,¹ Y. Chen,¹ Y. B. Chen,¹ Y. Q. Chen,¹ B. S. Cheng,¹ X. Z. Cui,¹ H. L. Ding,¹ L. Y. Dong,¹ Z. Z. Du,¹ W. Dunwoodie,⁸ C. S. Gao,¹ M. L. Gao,¹ S. Q. Gao,¹ P. Gratton,¹² J. H. Gu,¹ S. D. Gu,¹ W. X. Gu,¹ Y. F. Gu,¹ Y. N. Guo,¹ S. W. Han,¹ Y. Han,¹ F. A. Harris,⁹ J. He,¹ J. T. He,¹ K. L. He,¹ M. He,⁶ D. G. Hitlin,² G. Y. Hu,¹ H. M. Hu,¹ J. L. Hu,¹ Q. H. Hu,¹ T. Hu,¹ X. Q. Hu,¹ Y. Z. Huang,¹ J. M. Izen,¹² C. H. Jiang,¹ Y. Jin,¹ B. D. Jones,¹² Z. J. Ke,¹ M. H. Kelsey,² B. K. Kim,¹² D. Kong,⁹ Y. F. Lai,¹ P. F. Lang,¹ A. Lankford,¹⁰ C. G. Li,¹ D. Li,¹ H. B. Li,¹ J. Li,¹ P. Q. Li,¹ R. B. Li,¹ W. Li,¹ W. G. Li,¹ X. H. Li,¹ X. N. Li,¹ H. M. Liu,¹ J. Liu,¹ R. G. Liu,¹ Y. Liu,¹ X. C. Lou,¹² B. Lowery,¹² F. Lu,¹ J. G. Lu,¹ X. L. Luo,¹ E. C. Ma,¹ J. M. Ma,¹ R. Malchow,³ H. S. Mao,¹ Z. P. Mao,¹ X. C. Meng,¹ J. Nie,¹ S. L. Olsen,⁹ J. Oyang,² D. Paluselli,⁹ L. J. Pan,⁹ J. Panetta,² F. Porter,² N. D. Qi,¹ X. R. Qi,¹ C. D. Qian,⁷ J. F. Qiu,¹ Y. H. Qu,¹ Y. K. Que,¹ G. Rong,¹ M. Schernau,¹⁰ Y. Y. Shao,¹ B. W. Shen,¹ D. L. Shen,¹ H. Shen,¹ X. Y. Shen,¹ H. Y. Sheng,¹ H. Z. Shi,¹ X. F. Song,¹ J. Standifird,¹² F. Sun,¹ H. S. Sun,¹ Y. Sun,¹ Y. Z. Sun,¹ S. Q. Tang,¹ W. Toki,³ G. L. Tong,¹ G. S. Varner,⁹ F. Wang,¹ L. S. Wang,¹ L. Z. Wang,¹ Meng Wang,¹ P. Wang,¹ P. L. Wang,¹ S. M. Wang,¹ T. J. Wang,^{1,*} Y. Y. Wang,¹ M. Weaver,² C. L. Wei,¹ Y. G. Wu,¹ D. M. Xi,¹ X. M. Xia,¹ P. P. Xie,¹ Y. Xie,¹ Y. H. Xie,¹ G. F. Xu,¹ S. T. Xue,¹ J. Yan,¹ W. G. Yan,¹ C. M. Yang,¹ C. Y. Yang,¹ J. Yang,¹ W. Yang,³ X. F. Yang,¹ M. H. Ye,¹ S. W. Ye,¹¹ Y. X. Ye,¹¹ C. S. Yu,¹ C. X. Yu,¹ G. W. Yu,¹ Y. H. Yu,⁴ Z. Q. Yu,¹ C. Z. Yuan,¹ Y. Yuan,¹ B. Y. Zhang,¹ C. C. Zhang,¹ D. H. Zhang,¹ Dehong Zhang,¹ H. L. Zhang,¹ J. Zhang,¹ J. W. Zhang,¹ L. S. Zhang,¹ Q. J. Zhang,¹ S. Q. Zhang,¹ X. Y. Zhang,⁶ Y. Y. Zhang,¹ D. X. Zhao,¹ H. W. Zhao,¹ Jiawei Zhao,¹¹ J. W. Zhao,¹ M. Zhao,¹ W. R. Zhao,¹ Z. G. Zhao,¹ J. P. Zheng,¹ L. S. Zheng,¹ Z. P. Zheng,¹ B. Q. Zhou,¹ G. P. Zhou,¹ H. S. Zhou,¹ L. Zhou,¹ K. J. Zhu,¹ Q. M. Zhu,¹ Y. C. Zhu,¹ Y. S. Zhu,¹ and B. A. Zhuang¹

(BES Collaboration)

¹*Institute of High Energy Physics, Beijing 100039, People's Republic of China*

²*California Institute of Technology, Pasadena, California 91125*

³*Colorado State University, Fort Collins, Colorado 80523*

⁴*Hangzhou University, Hangzhou 310028, People's Republic of China*

⁵*Peking University, Beijing 100871, People's Republic of China*

⁶*Shandong University, Jinan 250100, People's Republic of China*

⁷*Shanghai Jiaotong University, Shanghai 200030, People's Republic of China*

⁸*Stanford Linear Accelerator Center, Stanford, California 94309*

⁹*University of Hawaii, Honolulu, Hawaii 96822*

¹⁰*University of California at Irvine, Irvine, California 92717*

¹¹*University of Science and Technology of China, Hefei 230026, People's Republic of China*

¹²*University of Texas at Dallas, Richardson, Texas 75083-0688*

(Received 13 January 1999; revised manuscript received 7 July 1999)

A sample of 3.79×10^6 $\psi(2S)$ events is used to study the decays of charmonium to axial-vector plus pseudoscalar mesons. The branching fraction for the decay $\psi(2S) \rightarrow b_1^\pm(1235)\pi^\mp$ agrees with expectations based on scaling the corresponding J/ψ branching fraction. Flavor-SU(3)-violating $K_1(1270)$ - $K_1(1400)$ asymmetries with opposite character for $\psi(2S)$ and J/ψ decays are observed. This contrasting behavior cannot be accommodated by adjustments of the singlet-triplet mixing angle.

PACS numbers: 13.25.Gv

In perturbative QCD, the dominant process for hadronic decays of both the J/ψ and the $\psi(2S)$ is annihilation into three gluons followed by the hadronization of these gluons into physically observable hadrons. The similarity between the parton-level final states has led to the conjecture that the ratio of the J/ψ and $\psi(2S)$ decay branching fractions into any exclusive final state X_h is given by the ratio of the square of the wave function at the origin of the constituent $c\bar{c}$ quark state, which is well determined from the dilepton decay rates [1],

$$\frac{\mathcal{B}[\psi(2S) \rightarrow X_h]}{\mathcal{B}[J/\psi \rightarrow X_h]} \simeq \frac{\mathcal{B}[\psi(2S) \rightarrow e^+e^-]}{\mathcal{B}[J/\psi \rightarrow e^+e^-]} = 0.141 \pm 0.012.$$

This conjecture is sometimes referred to as *the 14% rule* [2]. Although this conjecture seems to work reasonably well for a number of decay channels, it fails badly in the case of $\psi(2S)$ two-body decays to vector plus pseudoscalar meson final states—the decay $\psi(2S) \rightarrow \rho\pi$ is suppressed relative to the 14% rule expectation by more than a factor

of 50 [3,4]. This conundrum is commonly called the $\rho\pi$ puzzle [5]. In addition, the BES group has reported suppressions by factors of at least 3 in the vector plus tensor meson final states: $K^*K_2^*$, ρa_2 , ωf_2 , and $\phi f_2'$ [6]. To date, no convincing evidence has been uncovered for hadronic $\psi(2S)$ decays that are enhanced relative to the 14% rule expectation. Since at least one explanation for the $\rho\pi$ puzzle involves a mechanism that suppresses all $\psi(2S)$ decays to lowest-lying two-body mesons final states [7], it is useful to examine all possibilities. Here we report first measurements of $\psi(2S)$ decays to axial-vector plus pseudoscalar mesons.

There are two lowest-lying axial-vector-meson octets. These correspond to the singlet (1P_1) and triplet (3P_1) spin configurations of two quarks in a P -wave orbital angular momentum state. The nonstrange, isospin $I = 1$ members of the two octets have opposite G parity: the $b_1(1235)$ is in the 1P_1 octet and has $G = +1$, while the $a_1(1260)$ is in the 3P_1 octet and has $G = -1$. Since strong decays of the J/ψ and $\psi(2S)$ conserve G parity, decays to the axial-vector-pseudoscalar (AP) pair $b_1\pi$ are allowed and seen in J/ψ decays; decays to $a_1\pi$ final states are forbidden and not seen in J/ψ decays.

The strange members of the 3P_1 and 1P_1 octets, the K_A and K_B , respectively, are mixtures of the observed physical states, the $K_1(1270)$ and the $K_1(1400)$, where

$$K_A = \cos\theta K_1(1400) + \sin\theta K_1(1270), \quad (1)$$

$$K_B = \cos\theta K_1(1270) - \sin\theta K_1(1400), \quad (2)$$

and the mixing angle is near $\theta \approx 45^\circ$ [8]. The dominant $K_1(1270)$ decay mode is to $K\rho$ ($B = 42\% \pm 6\%$); the $K_1(1400)$ decays almost always to $K^*\pi$ ($B = 94\% \pm 6\%$).

In the limit of strict flavor-SU(3) symmetry, the amplitudes for two-body decays to conjugate mesons in the same pair of octets should be equal. Thus, since decays to $a_1\pi$ are forbidden by G parity, decays to $K_A\bar{K}$ are disallowed by SU(3), and one expects relatively pure $K_B\bar{K}$ final states in J/ψ and $\psi(2S)$ decays. And, since $\theta \approx 45^\circ$, there should be roughly equal amounts of $K_1(1270)$ and $K_1(1400)$.

This analysis is based on a sample of $(3.79 \pm 0.31) \times 10^6$ $e^+e^- \rightarrow \psi(2S)$ events [9], collected in the BES detector at the BEPC storage ring. The BES detector is described in some detail in Ref. [10]. The features that are most important for the analysis reported here are the 40-layer main cylindrical drift chamber (MDC), the 48-scintillation counter time-of-flight (TOF) system, and the 12-layer lead-gas barrel electromagnetic shower counter (BSC). These are all situated in a 0.4 T solenoidal magnetic field. Charged particle track trajectories are measured in the MDC with a momentum resolution of $\sigma_p/p = 1.7\%\sqrt{1+p^2}$ (p in GeV). The directions and energies of high energy γ rays are measured in the BSC with angular and energy resolutions of $\sigma_\phi = 4.5$ mrad, $\sigma_\theta = 12$ mrad, and $\sigma_E/E = 0.22/\sqrt{E}$ (E in GeV), respectively. We re-

strict our analysis to photons and charged tracks that are in the polar angle region $|\cos\theta| < 0.80$. For hadron tracks the time resolution of the barrel TOF is about 450 ps and the dE/dx resolution is about 11%, allowing for a π/K separation up to 600 MeV. For the combination of tracks that passes the kinematic fit with the best χ^2 , the dE/dx and TOF information is used to determine the probability that the candidate kaon tracks are consistent with being kaons. If the candidate kaon tracks have a probability less than 10%, the event is discarded.

Since the dominant decay mode of the b_1 is $b_1 \rightarrow \omega\pi$, we apply a five-constraint kinematic fit to events of the type $\psi(2S) \rightarrow \pi^+\pi^-\pi^+\pi^-\gamma\gamma$, where the $\gamma\gamma$ invariant mass is further constrained to be equal to M_{π^0} . The $\pi^+\pi^-\pi^0$ mass distribution for events that pass the five-constraint fit is shown in Fig. 1a, where there is a prominent peak. The peak is well fit with a Breit-Wigner shape with mass and width of the $\omega(782)$ convoluted with a Gaussian resolution function with $\sigma = 9.6$ MeV. We identify the best $\pi^+\pi^-\pi^0$ combination with invariant mass in the range $M_\omega \pm 30$ MeV as an ω candidate. Figure 1b shows the $\omega\pi$ mass distribution for events where the $\pi^+\pi^-$ pair recoiling against the ω has an invariant mass greater than 1.55 GeV. The latter requirement reduces the contamination from ωf_2 final states. The peak in Fig. 1b is well fit with an S -wave Breit-Wigner function with mass and width fixed at the Particle Data Group (PDG) values for the b_1 ($M_{b_1} = 1.232$ and $\Gamma_{b_1} = 0.142$ GeV) and a background shape that has a phase-space behavior at threshold that evolves to a constant level at higher masses. There are 79.8 ± 12.1 events in the fitted b_1 meson signal peak [11].

Using the detection efficiency of 0.046 ± 0.003 , which was determined from a Monte Carlo simulation, we

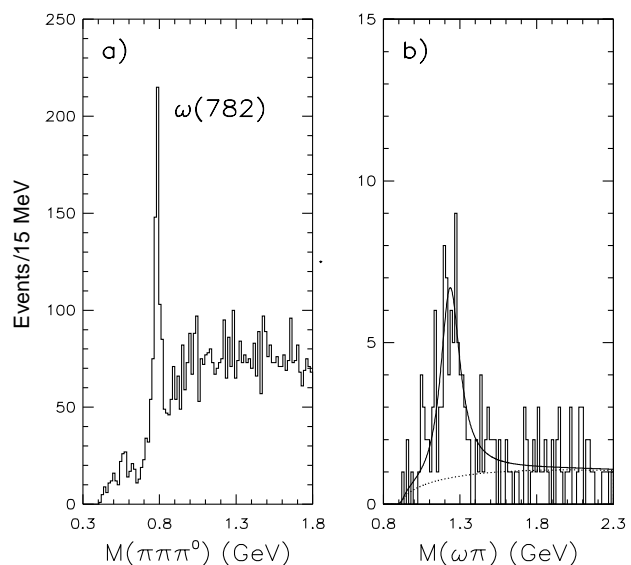


FIG. 1. The (a) $\pi^+\pi^-\pi^0$ and (b) $\omega\pi^\pm$ mass distributions from $\psi(2S) \rightarrow \pi^+\pi^-\pi^+\pi^-\pi^0$ events. The curve in (b) is a fit to the b_1 resonance plus a smooth background function.

measure a branching fraction of [12]

$$\mathcal{B}[\psi(2S) \rightarrow b_1^\pm \pi^\mp] = (5.2 \pm 0.8 \pm 1.0) \times 10^{-4},$$

where the first error is statistical and the second is systematic [13]. The result is higher than, but consistent with, the 14% rule expectation applied to the PDG result for the J/ψ [14].

For the $K_1\bar{K}$ decays, we select events of the type $\psi(2S) \rightarrow K^+K^-\pi^+\pi^-$ on the basis of the quality of a four-constraint kinematic fit. This final state includes the dominant $K_1^\pm(1270)$ and $K_1^\pm(1400)$ decay channels. We identify $\pi^+\pi^-$ pairs with invariant mass in the range $M_\rho \pm 150$ MeV as $\rho(770)$ candidates and $K^\pm\pi^\mp$ pairs with invariant mass in the range $M_{K^*} \pm 50$ MeV as $K^*(892)$ candidates.

The $K^\pm\rho$ mass distribution exhibits a strong enhancement near $M_{K\rho} = 1.27$ GeV, as shown in Fig. 2a. We fit the $K^\pm\rho^0$ mass distribution with a specially devised function, $f_{K\rho}$, that takes into account the distortions to the line shape caused by the restricted phase space available for the $K_1(1270) \rightarrow K\rho$ decay [15]. This plus a smooth background function that has a phase-space behavior near threshold provides an adequate fit to the data for masses below 2.0 GeV and yields a $K_1(1270)$ signal of 53.5 ± 9.5 events [11]. Using the detection efficiency of 0.085 ± 0.012 , we determine the branching fraction result of [16]

$$\mathcal{B}[\psi(2S) \rightarrow K_1^\pm(1270)K^\mp] = (10.0 \pm 1.8 \pm 2.1) \times 10^{-4}.$$

In the $K^*\pi^\pm$ invariant mass distribution, shown in Fig. 2b, there is little evidence for a $K_1(1400)$ signal. Since the $K\rho$ and $K^*\pi$ selection cuts are not mutually

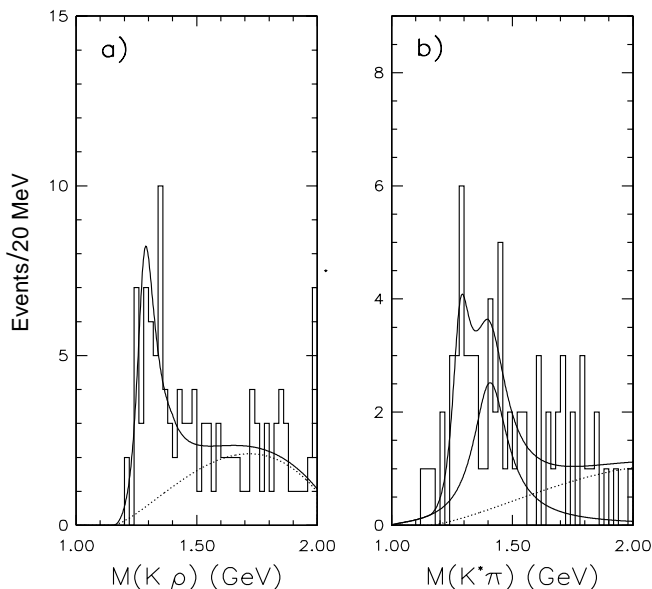


FIG. 2. The (a) $K^\pm\rho^0$ and (b) $K^{*0}\pi^\pm$ mass distributions from $\psi(2S) \rightarrow K^+K^-\pi^+\pi^-$ events. Note the difference in the vertical scales. The curves are the results of the fits discussed in the text.

exclusive, some feedthrough from $K_1(1270) \rightarrow K\rho$ into the $K^*\pi$ channel is expected, and seen. The smooth curve in Fig. 2b is the result of a fit using $f_{K\rho}$ for the $K_1(1270)$, an S -wave Breit-Wigner with mass and width fixed at the PDG values for the $K_1(1400)$ and a smooth background shape as was used for the $K\rho$ distribution. The resulting 29.8 ± 9.2 $K_1(1400) \rightarrow K^*\pi$ events and the efficiency of 0.090 ± 0.012 are used to derive a 90% C.L. upper limit of [17]

$$\mathcal{B}[\psi(2S) \rightarrow K_1^\pm(1400)K^\mp] < 3.1 \times 10^{-4} \quad 90\% \text{ C.L.}$$

Contrary to flavor-SU(3) expectations, the $\psi(2S) \rightarrow K_1(1400)\bar{K}$ branching fraction is smaller than that for the $K_1(1270)\bar{K}$ channel by at least a factor of 3. To accommodate this with the mixing angle, a value of $\theta < 29^\circ$ would be required.

In the absence of any published results for J/ψ decays to these channels, we used the $\psi(2S) \rightarrow \pi^+\pi^-J/\psi$ cascade events in our $\psi(2S)$ data sample to make a first measurement of the branching fractions for $J/\psi \rightarrow K_1(1270)\bar{K}$ and $K_1(1400)\bar{K}$. We select events that fit a five-constraint fit to the $\psi(2S) \rightarrow \pi^+\pi^-J/\psi$; $J/\psi \rightarrow K^+K^-\pi^+\pi^-$ hypothesis. We use the particle species assignment that gives the best χ^2 value, and we use the same $K\rho$ and $K^*\pi$ event selection criteria that are used for the analysis of direct $\psi(2S)$ decays.

In contrast to the case for the $\psi(2S)$, the $K\rho$ mass spectrum in $J/\psi \rightarrow K^+K^-\pi^+\pi^-$ decays, shown in Fig. 3a, has little evidence for the $K_1(1270)$. The small $K_1(1270)$ signal of 7.7 ± 5.8 $K_1(1270)$ events [18] and the efficiency of 0.025 ± 0.004 are used to infer a 90% C.L. upper limit of [16,17]

$$\mathcal{B}[J/\psi \rightarrow K_1^\pm(1270)K^\mp] < 3.0 \times 10^{-3} \quad 90\% \text{ C.L.};$$

this is more than a factor of 2 below the result expected from applying the 14% rule to our result for $\psi(2S)$ decays to this channel.

In further contrast to the $\psi(2S)$, the $K^{*0}\pi^\pm$ mass distribution for the J/ψ decays, shown in Fig. 3b, exhibits a clear $K_1(1400)$ signal; the fit to the $K^*\pi$ mass spectrum yields 59.0 ± 13.1 events in the $K_1(1400)$ signal [11]. The related efficiency is 0.030 ± 0.004 . We find

$$\mathcal{B}[J/\psi \rightarrow K_1^\pm(1400)K^\mp] = (3.8 \pm 0.8 \pm 1.2) \times 10^{-3},$$

which is above our upper limit for the $K_1(1270)\bar{K}$ mode, indicating a flavor-SU(3) violation in J/ψ decays that is opposite to that seen in $\psi(2S)$ decays. Accommodating this effect in J/ψ decays by adjusting the mixing angle would require a value of $\theta > 48^\circ$, in contradiction to the $\theta < 29^\circ$ result from $\psi(2S)$ decays.

In conclusion, we report first measurements for the $\psi(2S) \rightarrow b_1^\pm \pi^\mp$ and $K_1^\pm(1270)K^\mp$ decay branching fractions and a 90% C.L. upper limit for $\mathcal{B}[\psi(2S) \rightarrow K_1^\pm(1400)K^\mp]$. We find that two of the AP decays are relatively strong exclusive hadron channels for the $\psi(2S)$. In addition, we report the first observation of the $J/\psi \rightarrow K_1^\pm(1400)K^\mp$ decay mode and a 90% C.L. upper limit for $J/\psi \rightarrow K_1^\pm(1270)K^\mp$.

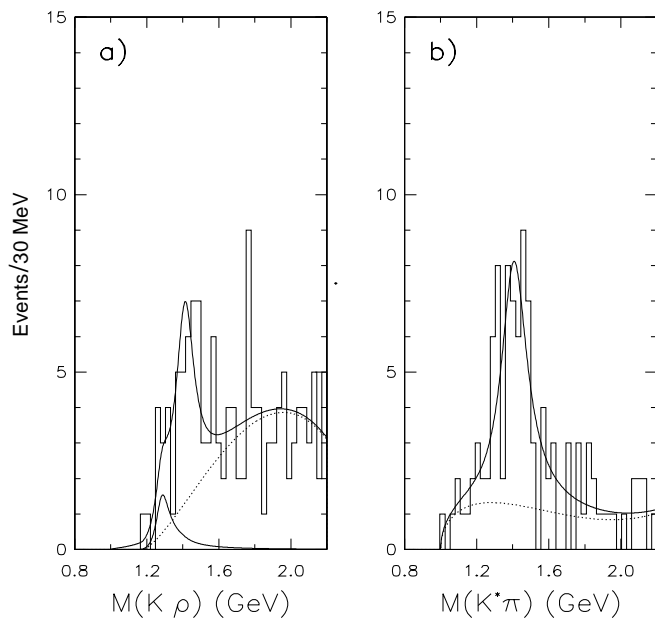


FIG. 3. The (a) $K^\pm \rho^0$ and (b) $K^{*0} \pi^\pm$ mass distributions from $J/\psi \rightarrow K^+ K^- \pi^+ \pi^-$ decays. The curve is the result of the fit described in the text. A $K_1(1270)$ signal is not needed to get an acceptable fit to the $K^{*0} \pi^\pm$ distribution.

The $\psi(2S) \rightarrow K_1(1270) \bar{K}$ result is the first observation of an exclusive $\psi(2S)$ two-body meson decay process that is enhanced relative to the J/ψ in the context of the 14% rule. This result as well as the lack of suppression in the $b_1 \pi$ channel rule out explanations for the $\rho \pi$ puzzle that suppress all $\psi(2S)$ decays to lowest lying two-body meson final states. In addition, we observe flavor-SU(3)-violating $K_1(1270)$ - $K_1(1400)$ asymmetries that have opposite character for the $\psi(2S)$ and J/ψ . This cannot be accommodated by adjustments of the singlet-triplet mixing angle [19].

We acknowledge the strong efforts of the BEPC staff and the helpful assistance we received from the members of the IHEP computing center. One of us (D.P.) thanks M. Suzuki and F. Liu for helpful discussions. The work of the BES Collaboration is supported in part by the National Natural Science Foundation of China under Contract No. 19290400, by the Chinese Academy of Sciences under Contracts No. H-10 and No. E-01 (IHEP), and by the Department of Energy under Contracts No. DE-FG03-92ER40701 (Caltech), No. DE-FG03-93ER40788 (Colorado State University), No. DE-AC03-76SF00515 (SLAC), No. DE-FG03-91ER40679 (UC Irvine), No. DE-FG03-94ER40833 (U Hawaii), and No. DE-FG03-95ER40925 (UT Dallas).

*Deceased.

- [1] Particle Data Group, C. Caso *et al.*, *Eur. Phys. J. C* **3**, 1 (1998), and references therein.
 [2] If the change in the QCD coupling strength $\alpha_s(Q^2)$ from $Q^2 = M_{J/\psi}^2$ to $M_{\psi(2S)}^2$ is considered, the expectation for this ratio is lowered to 0.12 ± 0.02 .

- [3] Mark II Collaboration, M. E. B. Franklin *et al.*, *Phys. Rev. Lett.* **51**, 963 (1983).
 [4] BES Collaboration, J. Z. Bai *et al.*, in *Proceedings of the 1995 International Symposium on Lepton and Photon Interactions at High Energies, Beijing, China* (World Scientific, Singapore, 1996).
 [5] S. J. Brodsky, G. P. LePage, and S. F. Tuan, *Phys. Rev. Lett.* **59**, 621 (1987). See also W.-S. Hou and A. Soni, *Phys. Rev. Lett.* **50**, 569 (1983).
 [6] BES Collaboration, J. Z. Bai *et al.*, *Phys. Rev. Lett.* **81**, 5080 (1998).
 [7] M. Chaichian and N. A. Törnqvist, *Nucl. Phys.* **B323**, 75 (1989).
 [8] See, for example, H. G. Blundell, S. Godfrey, and B. Phelps, *Phys. Rev. D* **53**, 3712 (1996); M. Suzuki, *Phys. Rev. D* **47**, 1252 (1993), and references therein.
 [9] BES Collaboration, J. Z. Bai *et al.*, *Phys. Rev. D* **58**, 092006 (1998). The determination of the number of $\psi(2S)$ events uses $B[\psi(2S) \rightarrow \pi^+ \pi^- J/\psi] = (32.4 \pm 2.6)\%$ [Particle Data Group, R. M. Barnett *et al.*, *Phys. Rev. D* **54**, 1 (1996)].
 [10] BES Collaboration, J. Z. Bai *et al.*, *Nucl. Instrum. Methods Phys. Res., Sect. A* **344**, 319 (1994); *Phys. Rev. Lett.* **69**, 3021 (1992).
 [11] The experimental mass resolution (σ) for $b_1 \rightarrow \omega \pi$ is 12 MeV, for $K_1(1270) \rightarrow K \rho$ is 17 MeV, and for $K_1(1400) \rightarrow K^* \pi$ is 18 MeV.
 [12] We assume that $b_1^+ \rightarrow \omega \pi^+$ branching fraction is 100%.
 [13] The systematic errors for all branching fractions in this paper include the error on the number of $\psi(2S)$ and the errors on the PDG branching fractions for all the intermediate channels to the final states. Uncertainties associated with the continuum contribution, the Monte Carlo simulation, particle identification, and the choice of cuts are also taken into account.
 [14] The PDG value for $B(J/\psi \rightarrow b_1^\pm \pi^\mp)$ is $(3.0 \pm 0.5) \times 10^{-3}$. As a check of our $\psi(2S)$ measurement, we applied the same procedures to the $J/\psi \rightarrow b_1 \pi$ decays from $\psi(2S) \rightarrow \pi^+ \pi^- J/\psi$ cascade decays and find a result that agrees within errors with the PDG value.
 [15] The function used to fit the $K_1(1270)$ is a convolution of an S -wave Breit-Wigner function with mass and width fixed at the PDG values for the $K_1(1270)$ with a P -wave Breit-Wigner function for the ρ meson. The requirement that the $\pi^+ \pi^-$ mass is within ± 150 MeV of the $\rho(770)$ is set in the limits of the convolution integral.
 [16] The $K^* \pi$ feedthroughs are taken into account both for ψ' and $J/\psi \rightarrow K_1(1270) \bar{K}$, and have efficiencies, respectively, of 0.032 ± 0.005 and 0.010 ± 0.002 . The errors on all efficiencies include the errors from Monte Carlo statistics and systematics added in quadrature.
 [17] The 90% C.L. limits are obtained by increasing the number of events from the fits by 1.28σ , where σ includes the error from the fit and the systematic error added in quadrature.
 [18] The spectrum is fit taking into account the $K_1(1400) \rightarrow K^* \pi$ feedthrough into the $K \rho$ channel.
 [19] Preliminary results from this analysis are discussed in the context of SU(3) symmetry breaking, in M. Suzuki, *Phys. Rev. D* **55**, 2840 (1997).