Charmonium Decays to Axialvector 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] B. A. Zhuang[1]

(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*

(November 6, 1998)

A sample of 3.79 million $\psi(2S)$ decays observed in the BES detector is used to study the process $\psi(2S) \to$ axialvector plus pseudoscalar mesons. The branching fraction for the decay $\psi(2S) \to b_1^{\pm}(1235)\pi^{\mp}$ agrees with expectations based on scaling the corresponding $J/\psi(1S)$ branching fraction. There is strong evidence for $\psi(2S) \to K_1^{\pm}(1270)K^{\mp}$ but not for $\psi(2S) \to K_1^{\pm}(1400)K^{\mp}$, in contradiction to expectations from strict flavor-SU(3) symmetry. We report the first measurement of a branching ratio for the former and an upper limit for the latter. A sample of J/ψ decays from the cascade process $\psi(2S) \to \pi^+\pi^- J/\psi$ is used to measure a branching fraction for $J/\psi(1S) \to K_1^{\pm}(1400)K^{\mp}$ decays that exceeds, and an upper limit for $\mathcal{B}(J/\psi(1S) \to K_1^{\pm}(1270)K^{\mp})$ that is below, expectations based on the $\psi(2S)$ results. This contrasting behavior between the J/ψ and the $\psi(2S)$ cannot be accommodated by an adjustment to the singlet-triplet axialvector mixing angle.

I. MOTIVATION

A. The 14% rule for hadronic $\psi(2S)$ decays

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 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]:

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

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 (VP) final states—the decay $\psi(2S) \to \rho\pi$ is suppressed relative to the 14% rule expectation by more than a factor of fifty [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 five in the vector plus tensor meson (VT) final states: $K^*\overline{K_2^*}$, 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 axialvector plus pseudoscalar mesons (AP).

B. The axialvector meson octets

There are two lowest-lying axialvector-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 non-strange, 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 axialvector 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 $\theta \simeq 45^0$ [8]. The dominant $K_1(1270)$ decay mode is to $K\rho$ (Br $= 42\pm 6\%$); the $K_1(1400)$ decays almost always to $K^*\pi$ (Br $= 94 \pm 6\%$).

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 $K_A\overline{K}$ are disallowed by SU(3) and one expects relatively pure $K_B\overline{K}$ final states in J/ψ and $\psi(2S)$ decays. And, since $\theta \simeq 45^0$, there should be roughly equal amounts of $K_1(1270)$ and $K_1(1400)$.

II. THE BES DETECTOR

This analysis is based on a sample of $e^+e^- \to \psi(2S)$ events collected in the BES detector at the BEPC storage ring. The BES detector is described in some detail in ref. [9]. 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. Particle identification is provided by drift chamber dE/dx measurements and from particle velocities as determined from the TOF system. For this analysis, we only use photons and charged tracks that are in the polar angle region $|\cos\theta| \leq 0.8$. This restricts the analysis to particles that traverse all 40 layers of the MDC and are well contained in the BSC. For each charged track, the dE/dx and TOF information is used to determine the probability that the track is consistent with being a kaon; tracks with a probability of more than 10% are considered candidate kaons, otherwise they are considered to be pions. The particle momentum measurements and identification assignments are further refined by the application of four- (4C) and five-constraint (5C) kinematic fits.

III. RESULTS

A. Determination of $\mathcal{B}(\psi(2S) \to b_1\pi)$

Since the dominant decay mode of the b_1 is $b_1 \to \omega\pi$, we apply a five constraint kinematic fit to events of the type

$$\psi(2S) \to \pi^+\pi^-\pi^+\pi^-\gamma\gamma,$$

where the $\gamma\gamma$ invariant mass is further constrained to be equal to $M_{\pi 0}$. The $\pi^+\pi^-\pi^0$ mass distribution for events that pass the 5-C fit is shown in Fig. 1a, where there is a prominent $\omega(782)$ peak. We identify $\pi^+\pi^-\pi^0$ combinations with invariant mass in the range $M_{\pi^+\pi^-\pi^0} = M_\omega \pm 40$ MeV as ω candidates. In events with more than one candidate ω, we use the one with mass closest to M_ω.

Fig. 1b shows the $\omega\pi^\pm$ mass distribution for events where the recoiling $\pi^+\pi^-$ pair has an invariant mass greater than 1.55 GeV. The latter requirement eliminates any possible contamination from ωf_2 final states. The peak in Fig. 1b is well fit with a s-wave Breit Wigner function with mass and width fixed at the 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 behaviour at threshold that evolves to a constant level at higher masses. There are 83.9 ± 12.7 in the fitted b_1 meson signal peak.

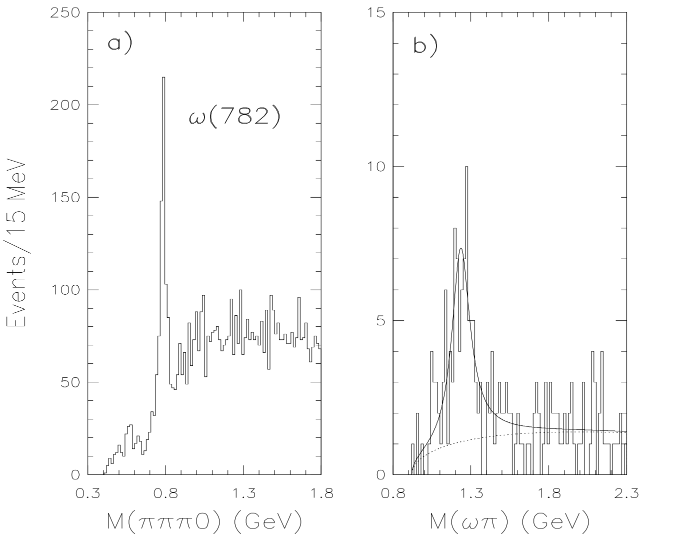

FIG. 1. The **a)** $\pi^+\pi^-\pi^0$ and **b)** $\omega\pi^\pm$ mass distributions from $\psi(2S) \to \pi^+\pi^-\pi^+\pi^-\pi^0$ events. The curve in **b)** is a fit to the b_1 resonance plus a smooth background function (shown as a dotted line).

Using the detection efficiency determined from a Monte Carlo simulation of the experiment and a total number of (3.79 ± 0.31) million $\psi(2S)$ decays in our event sample inferred from the observed number of $\psi(2S) \to \pi^+\pi^- J/\psi$ cascade events [10], we determine a $\psi(2S) \to b_1\pi$ branching fraction of [11]

$$\mathcal{B}(\psi(2S) \to b_1^\pm\pi^\mp) = (5.3 \pm 0.8 \pm 0.8) \times 10^{-4},$$

where the first error is statistical and the second is systematic and includes uncertainties associated with the shape of the background under the b_1 peak and uncertainties in the acceptance calculations. The result is higher than, but consistent with, the 14% rule expectation applied to the PDG result for the J/ψ [12].

B. $\psi(2S) \to K_1(1270)\overline{K}$ and $K_1(1400)\overline{K}$

For the $K_1\overline{K}$ decays, we select events of the type $\psi(2S) \to K^+K^-\pi^+\pi^-$ on the basis of the quality of a 4-C kinematic fit. This final state includes the dominant $K_1^\pm(1270)$ and $K_1^\pm(1400)$ decay channels. Figs. 2a and 2b show the $\pi^+\pi^-$ and $K^\pm\pi^\mp$ invariant masses for the selected selected events, where signals for a $\rho(770)$ and a $K^*(892)$ are evident. 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. 3a. 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 $K_1(1270) \to K\rho$ decay [13]. This plus a smooth background function that has a phase-space behaviour near threshold provide 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.

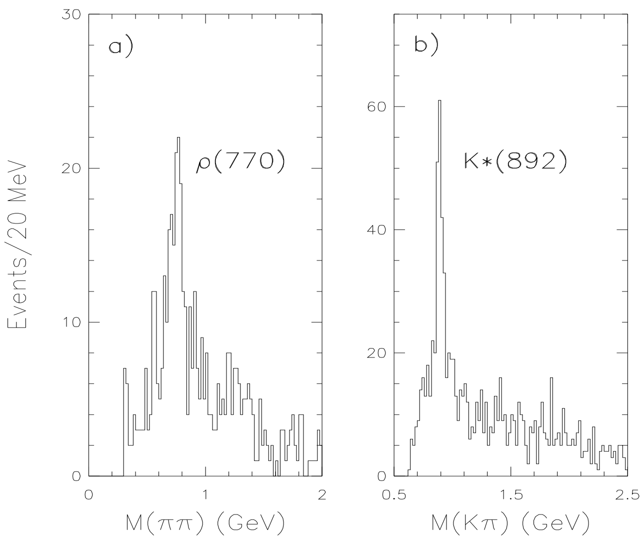

FIG. 2. The **a)** $\pi^+\pi^-$ and **b)** $K^\pm\pi^\mp$ mass distributions in the selected $\psi(2S) \to K^+K^-\pi^+\pi^-$ event sample.

In the $K^*\pi^\pm$ invariant mass distribution, shown in Fig. 3b, there is no evidence for a $K_1(1400)$ signal. Since the $K\rho$ and $K^*\pi$ selection cuts are not mutually exclusive, some feedthrough from $K_1(1270) \to K\rho$ into the $K^*\pi$ channel is expected, and seen. The smooth curve in Fig. 3b 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. Since the $K^*\pi$ mass distribution can be adequately fit without any $K_1(1400)$, we derive a 90% CL upper limit of 41.6 $K_1(1400) \to K^*\pi$ events.

The resulting $K_1(1270)\overline{K}$ branching ratio is

$$\mathcal{B}(\psi(2S) \to K_1^\pm(1270)K^\mp) = (10.0 \pm 1.8 \pm 1.8) \times 10^{-4},$$

and the 90% CL upper limit for $K_1(1400)\overline{K}$ mode is

$$\mathcal{B}(\psi(2S) \to K_1^\pm(1400)K^\mp) < 2.9 \times 10^{-4} \quad 90\% \text{ CL}.$$

Contrary to flavor-SU(3) expectations, the $\psi(2S) \to K_1(1400)\overline{K}$ branching fraction is smaller than that for the $K_1(1270)\overline{K}$ channel by at least a factor of three. To accommodate this with the mixing angle, a value $\theta < 30^0$ would be required.

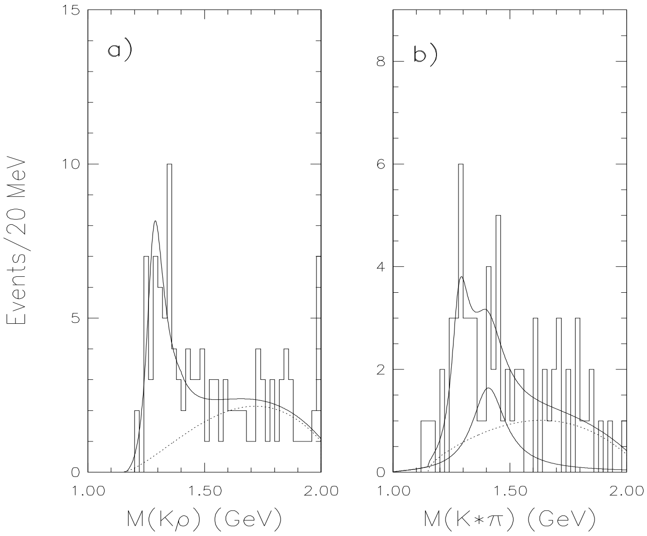

FIG. 3. The **a)** $K^{\pm}\rho^0$ and **b)** $K^{*0}\pi^{\pm}$ mass distributions from $\psi(2S) \to K^+K^-\pi^+\pi^-$ events. Note the difference in the vertical scales. The curves are the results of the fits discussed in the text.

C. $J/\psi \to K_1(1270)\overline{K}$ and $K_1(1400)\overline{K}$

In the absence of any published results for J/ψ decays to these channels, we used the $\psi(2S) \to \pi^+\pi^- J/\psi$ cascade events in our $\psi(2S)$ data sample to make a first measurement of the branching fractions for $J/\psi \to K_1(1270)\overline{K}$ and $K_1(1400)\overline{K}$. We select events that fit a five-constraint fit to the $\psi(2S) \to \pi^+\pi^- J/\psi; J/\psi \to K^+K^-\pi^+\pi^-$ hypothesis. We use the particle species assignment that gives the best χ^2 value, and reject events where the BES particle identification system unambiguously identifies as a pion a particle that the fit assigned as a kaon. 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 $J/\psi \to K^+K^-\pi^+\pi^-$ decays, shown in Fig. 4a, has little evidence for the $K_1(1270)$. Since we can find adequate fits to the spectrum with no $K_1(1270)$ signal, we use the $K_1(1270)$ signal shown in Fig. 4a to infer a 90% CL upper limit of 15.2 $K_1(1270)$ events. In further contrast to the $\psi(2S)$, the $K^{*0}\pi^{\pm}$ mass distribution for the J/ψ decays, shown in Fig. 4b, exhibits a clear $K_1(1400)$ signal; the fit to the $K^*\pi$ mass spectrum yields 59.0 ± 13.1 in the $K_1(1400)$ signal.

We determine a 90% CL upper limit for the $J/\psi \to K_1(1270)\overline{K}$ of

$$\mathcal{B}(J/\psi \to K_1^{\pm}(1270)K^{\mp}) < 2.9 \times 10^{-3} \quad 90\% \text{ CL};$$

this is more than a factor of two below the result expected from applying the 14% rule to our result for $\psi(2S)$ decays to this channel. Our result for the $J/\psi \to K_1(1400)\overline{K}$ branching fraction is

$$\mathcal{B}(J/\psi \to K_1^{\pm}(1400)K^{\mp}) = (3.8 \pm 0.8 \pm 0.5) \times 10^{-3},$$

which is above our upper limit for the $K_1(1270)\overline{K}$ 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 $\theta > 49^0$, in contradiction to the $\theta < 30^0$ result from $\psi(2S)$ decays.

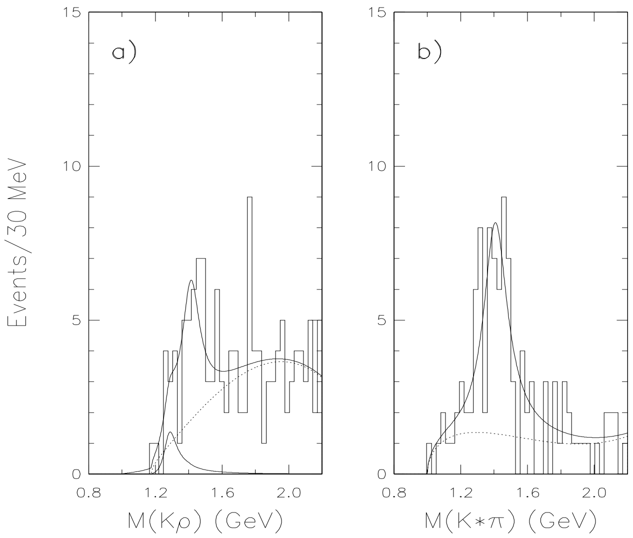

FIG. 4. The **a)** $K^{\pm}\rho^0$ and **b)** $K^{*0}\pi^{\pm}$ mass distributions from $J/\psi \to K^+K^-\pi^+\pi^-$ decays. The curve is the result of the fit described in the text. A $K_1(1270)$ signal is not needed to get an acceptable fit to the $K^{\pm}\pi^{\mp}$ distribution.

IV. SUMMARY

We report first measurements for the $\psi(2S) \to b_1^{\pm}\pi^{\mp}$ and $K_1^{\pm}(1270)K^{\mp}$ decay branching fractions and a 90% CL upper limit for $\mathcal{B}(\psi(2S) \to K_1^{\pm}(1400)K^{\mp})$. 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 $J/\psi \to K_1^{\pm}(1400)K^{\mp}$ decay mode and a 90% CL upper limit for $J/\psi \to K_1^{\pm}(1270)K^{\mp}$.

The $\psi(2S) \to K_1(1270)\overline{K}$ 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 characters for the $\psi(2S)$ and J/ψ. This can not be accommodated by adjustments of the singlet-triplet mixing angle.

V. ACKNOWLEDGEMENTS

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 for a helpful discussion. The work of the BES Collaboration is supported in part by the National Natural Science Foundation of China under Contract No. 19290400, the Chinese Academy of Sciences under contract No. KJ85 (IHEP), the China Postdoctoral Science Foundation, and by the U.S. Department of Energy under Contract Nos. DE-FG03-92ER40701 (Caltech), DE-FG03-93ER40788 (Colorado State University), DE-AC03-76SF00515 (SLAC), DE-FG03-91ER40679 (UC Irvine), DE-FG03-94ER40833 (U Hawaii), DE-FG03-95ER40925 (UT Dallas).

† Deceased.

[1] C. Caso *et al.* (Particle Data Group), Eur. Phys. J. **C3**, 1 (1998) and references therein.

[2] When the change in the QCD coupling strength $\alpha_s(Q^2)$ between $Q^2 = M^2_{J/\psi}$ and $M^2_{\psi(2S)}$ is taken into account, the expectation for the given ratio is lowered to 0.12 ± 0.02.

[3] M.E.B. Franklin *et al.* (Mark II Collaboration), Phys. Rev. Lett. **51**, 963 (1983).

[4] J.Z. Bai *et al.* (BES Collaboration), *Search for $\psi' \to$ Vector + Pseudoscalar Decays*, paper submitted to the 1995 International Symposium on Lepton and Photon Interactions at High Energies, Beijing, China.

[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] J.Z. Bai *et al.* (BES Collaboration), *$\psi(2S)$ hadronic decays to vector tensor final states*, to be published in Phys. Rev. Lett.

[7] M. Chaihian and N.A. Törnqvist, Nucl. Phys. **B323**, 75 (1989).

[8] See, for example, H.G. Blundell, S. Godfrey, and B. Phelps, Phys. Rev. **D53**, 3712 (1996), M. Suzuki, Phys. Rev. **D47**, 1252 (1993), and references cited therein.

[9] J.Z. Bai *et al.* (BES Collaboration), Nucl. Instr. and Meth. **A344**, 319 (1994) and Phys. Rev. Lett. **69**, 3021 1992.

[10] J.Z. Bai *et al.* (BES Collaboration), Phys. Rev. **D58**, 092006 (1998),

[11] We assume that $b_1^+ \to \omega\pi^+$ branching fraction is 100%.

[12] The PDG value for $Br(J/\psi \to b_1^\pm \pi^\mp)$ is $(3.0 \pm 0.5) \times 10^{-3}$. As a check of our $\psi(2S)$ measurement, we applied the same procedures to J/ψ's from $\psi(2S) \to \pi^+\pi^- J/\psi$ cascade decays and find a result that agrees within errors with the PDG value.

[13] 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 ρ meson Breit Wigner. The requirement that the $\pi^+\pi^-$ mass is within ± 150 MeV of the $\rho(770)$ is set in the limits of the convolution integral.