2nd DRAFT S.L.Olsen 6/27/96

Charmonium decays to Axialvector plus Pseudoscalar Mesons

The BES Collaboration

-ABSTRACT-

We use a sample of 3.4 million $\psi(2S)$ decays observed in the BES detector to study the process $\psi(2S) \to$ axialvector plus pseudoscalar mesons. We find a branching fraction for $\psi(2S) \to b_1(1235)\pi$ that exceeds 14%-rule extrapolations from the PDG value for the $J/\psi(1S)$. We find strong evidence for $\psi(2S) \to K_1(1270)\overline{K}$ but not for $\psi(2S) \to K_1(1400)\overline{K}$, in contradiction to expectations from strict flavor-SU(3) symmetry. We report first measurements of a branching ratio for the former and an upper limit for the latter. Using a sample of J/ψ decays from the cascade process $\psi(2S) \to \pi^+\pi^- J/\psi$, we measure a branching fraction for $J/\psi(1S) \to K_1(1400)\overline{K}$ decays that exceeds, and an upper limit for $Br(J/\psi(1S) \to K_1(1270)\overline{K})$ 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.

Submitted to the XXVIII International Conference on High Energy Physics, July 25-31, 1996, Warsaw Poland.

1 Motivation

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

The hadronic decays of both the $J/\psi(1S)$ and the $\psi(2S)$ are expected to proceed primarily via an 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]:

$$\frac{Br(\psi(2S) \to X_h)}{Br(J/\psi \to X_h)} = \frac{Br(\psi(2S) \to e^+e^-)}{Br(J/\psi \to e^+e^-)} = 0.147 \pm 0.023. \tag{1}$$

This conjecture is sometimes referred to as the *the 14% rule.* Although this conjecture seems to work reasonably well for a number of decay channels, it fails badly in $\psi(2S)$ decays to two-body vector plus pseudoscalar meson (VP) final states—the decay $\psi(2S) \to \rho\pi$ is supressed relative to 14% rule expectations by more than a factor of 60 [2][3]. In addition, the BES group has found suppressions by at least factors of five in the vector plus tensor meson (VT) final states: $K^*\overline{K_2^*}$, ρa_2, and ωf_2 [4]. To date, no convincing evidence has been uncovered for hadronic $\psi(2S)$ decays that are enhanced relative to 14%-rule expectations. Here we report first measurements of $\psi(2s)$ decays to axialvector plus pseudoscalar mesons (AP).

1.2 The axialvector meson octets

There are two lowest-lying axialvector-meson octets. These correspond to the singlet ($^1P_1$) and triplet ($^3P_1$) spin states of two quarks in a p-wave orbital angular momentum state. The non-strange $I = 1$ 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 $G = -1$. The strong decays of the J/ψ and $\psi(2S)$ conserve G-parity: decays to the axialvector pseudoscalar (AP) pair $b_1\pi$ are G-parity allowed and seen in J/ψ decays; decays to $a_1\pi$ final states are G-parity forbidden and not seen in J/ψ decays.

1.2.1 The strange axialvector mesons

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

$$K_A = \cos\theta K_1(1270) + \sin\theta K_1(1400) \quad (2)$$

$$K_B = \cos\theta K_1(1400) - \sin\theta K_1(1270), \quad (3)$$

where the mixing angle is near $\theta = 45^0$ [5]. The dominant $K_1(1270)$ decay modes are to $K\rho$ (Br = 42%) and $K_2^*(1430)\pi$ (Br=28%). The $K_1(1400)$ decays almost always to $K^*\pi$ (Br = 92%).

Flavor-SU(3) symmetry says that the amplitude 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. Since $\theta \simeq 45^0$, there should be roughly equal amounts of $K_1(1270)$ and $K_1(1400)$.

2 Results

2.1 Determination of $Br(\psi(2S) \to b_1\pi)$

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

$$\psi(2S) \to \pi^+\pi^-\pi^+\pi^-\gamma\gamma, \quad (4)$$

where the the invariant mass of the two $\gamma's$ is constrained to $M_{\pi 0}$. From the selected events, we require one $\pi^+\pi^-\pi^0$ combination has an invariant mass in the range $M_{\pi^+\pi^-\pi^0} = M_\omega \pm 60$ MeV and the mass of the remaining $\pi^+\pi^-$ pair to be greater than 1.55 GeV. The latter requirement eliminates any possible contamination from ωf_2 final states.

The resulting $\omega(780)\pi^\pm$ mass distribution, shown in Fig. 1, is well fit with a s-wave Breit Wigner function with the resonance mass and width fixed at the PDG values for the b_1, of $M_0 = 1.232$ and $\Gamma_0 = 0.155$ GeV.

Using an acceptance determined from from a Monte Carlo simulation of the experiment and a total number of $\psi(2S)$ decays in our event sample inferred from the observed number of $\psi(2S) \to \pi^+\pi^- J/\psi$ cascade events [6], we determine a $\psi(2S) \to b_1\pi$ branching fraction of

$$Br(\psi(2S) \to b_1^+\pi^- \ + \ cc) = (7.3 \pm 1.9) \times 10^{-4}, \quad (5)$$

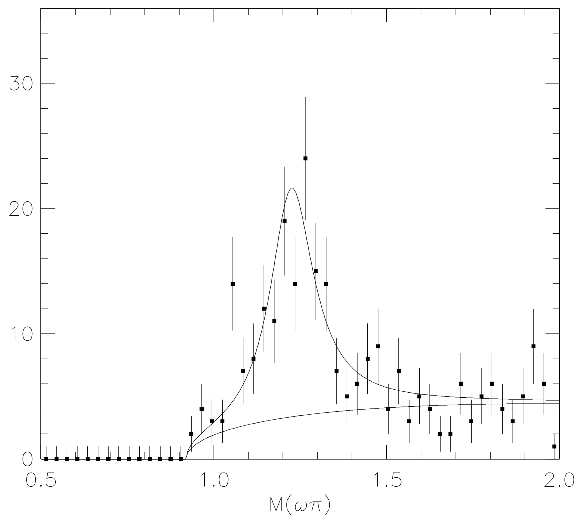

Figure 1: The $\omega\pi^{\pm}$ mass distribution showing a fit using to a b_1 resonance and a smooth background function.

where the error includes uncertainties associated with the shape of the background under the b_1 peak. This is about a factor of two ($\sim 2\sigma$) above the 14% rule expectation applied to the PDG result for the J/ψ [7].

2.2 $\psi(2S) \to K_1(1270)K$ and $K_1(1400)K$

For the K_1K decays, we select events of the type $\psi(2S) \to K^+K^-\pi^+\pi^-$ on the basis of the quality of a four-constraint kinematic fit. This final state includes the dominant $K_1(1270)$ and $K_1(1400)$ decay channels.

Using events with $\pi^+\pi^-$ pairs that have an invariant within ± 150 MeV of the nominal $\rho(770)$, we find a $K^{\pm}\rho^0$ mass distribution with a strong enhancement near $M_{K\rho} = 1.27$ GeV, as shown in Fig. 2. Since the restricted phase space for the $K_1(1270) \to K\rho$ decay distorts the resonance shape for this mode, we fit the $K^{\pm}\rho$ mass distribution of with a specially devised function $f_{K\rho}$ that takes these effects into account [8]. This function and a smooth background provides an adequate fit the data for masses below 2.0 GeV, as can be seen in the figure.

Using events with $K^{\pm}\pi^{\mp}$ pairs that are within ± 50 MeV of the $K^*(890)$, we find the $K^{*0}\pi^{\pm}$ mass distribution shown in Fig. 3. Here there is no strong evidence for a

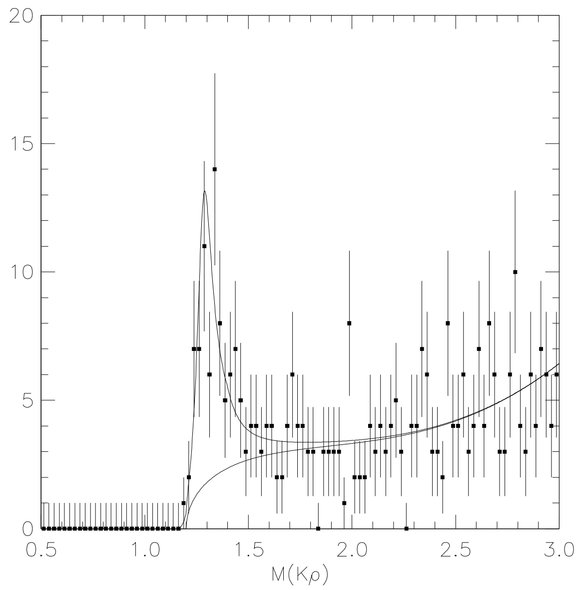

Figure 2: Fit to the $K^+\rho^0$ mass distribution using the function $f_{K\rho}$ for the K_1(1270 line shape and a smooth curve to parameterize the background.

$K_1(1400)$ signal. We fit the region below 1.9 GeV to $f_K\rho$[1] plus an s-wave Breit Wigner with mass and width fixed at the PDG values for the $K_1(1400)$ and a background function. The curve in Fig. 3 shows the fit that maximizes the $K_1(1400)$ contribution by parameterizing all of the background in the K_1 as the tail of a higher mass Breit Wigner resonance. Since, even in this case, the mass distribution can be adequately fit without any $K_1(1400)$, we use this number to derive a 90% CL upper limit on the $K_1(1400)$ yield.

The resulting $K_1(1270)K$ branching ratio is

$$Br(\psi(2S) \to K_1^+(1270)K^- \ + \ cc) = (7.6 \pm 1.7) \times 10^{-4}, \tag{6}$$

where the error includes uncertainties in the shape of the background under the K_1 peak. The 90% CL upper limit for $K_1(1400)K$ mode is

$$Br(\psi(2S) \to K_1^+(1400)K^- \ + \ cc) < 2.7 \times 10^{-4} \quad 90\% \text{ CL}. \tag{7}$$

Contrary to flavor-SU(3) expectation of roughly equal amounts, the $K_1(1400)K$ branching ratio is smaller than the $K_1(1270)K$ mode by at least a factor of three. To accommodate with the mixing angle, a value $\theta < 30^0$ is required.

[1]The $K\rho$ and $K^*\pi$ selection cuts are not mutually exclusive. Some feedthrough from $K\rho$ into the $K^*\pi$ channel is expected.

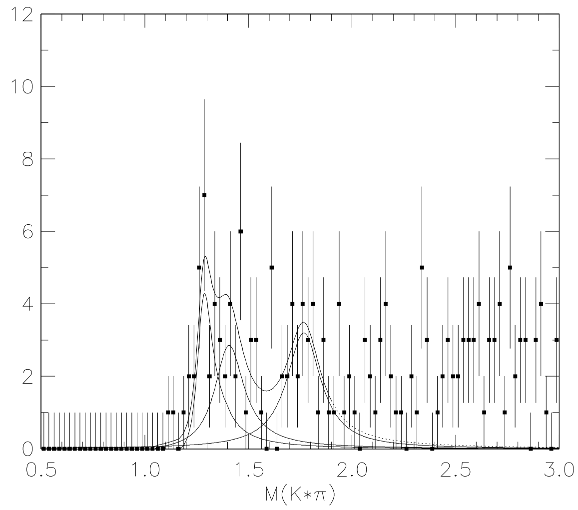

Figure 3: Fit to the $K^{*0}\pi^{\pm}$ mass distribution. Here we using a Breit Wigner at higher mass as a background shape in order to maximize any possible $K_1(1400)$ contribution.

2.3 $J/\psi \to K_1(1270)K$ and $K_1(1400)K$

In the absence of any published results on 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 these branching ratios 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 hypothesis $\psi(2S) \to \pi^+\pi^- J/\psi$; $J/\psi \to K + K^-\pi^+\pi^-$. 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 as are used for direct $\psi(2S)$ decays.

In contrast to the $\psi(2S)$, the $K\rho$ mass spectrum, shown in Fig. 4 shows little evidence for the $K_1(1270)$. We can find adequate fits to the spectrum with no $K_1(1270)$. The fit shown in the figure is used to determine a 90% CL upper limit on the number of $K_1(1270)$ events.

In contrast, the $K^*\pi$ mass distribution for the J/ψ decays, shown in Fig. 5, exhibits a clear $K_1(1400)$ signal. We determine the number of $K_1(1400)$ events from fits to the $K^*\pi$ mass spectrum shown in Fig. 5.

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

$$Br(J/\psi \to K_1^+(1270)K^- \ + \ cc) < 1.8 \times 10^{-3} \ \ 90\% \text{ CL}, \tag{8}$$

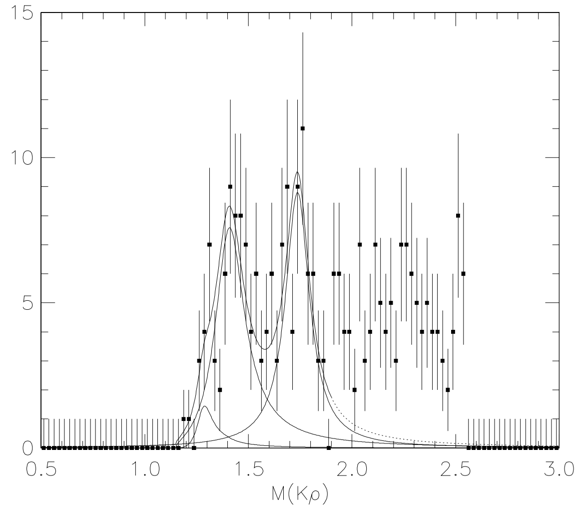

Figure 4: Fit to the $K^+\rho^0$ mass distribution from J/ψ decays using $f_{K\rho}$, an s-wave Breit Wigner with mass and width fixed at the PDG values for the $K_1(1400)$ and a background parameterized by a Breit Wigner resonsnce at higher masses.

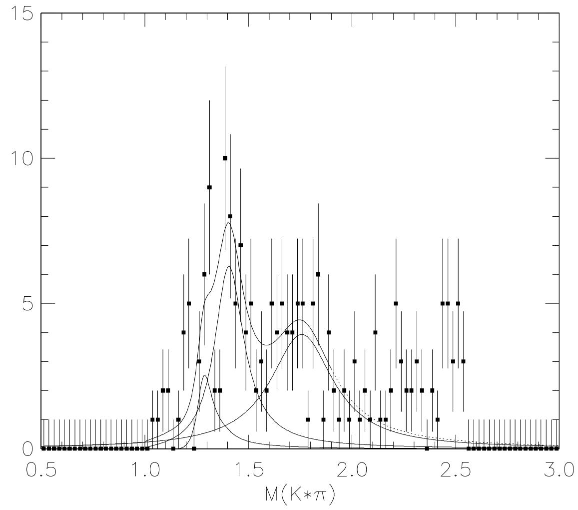

Figure 5: Fit to the $K^*\pi$ mass distribution from J/ψ decays using $f_{K\rho}$, an s-wave Breit Wigner with mass and width fixed at the PDG values for the $K_1(1400)$ and a background parameterized as a Breit Wigner resonance at higher masses.

which 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. The $J/\psi \to K_1(1400)K$ result

$$Br(J/\psi \to K_1^+(1400)K^- \ + \ cc) = (5.0 \pm 1.3) \times 10^{-3}, \tag{9}$$

is well 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 requires a value of $\theta > 60^0$, in contradiction to the $\theta < 30^0$ result from $\psi(2S)$ decays.

3 Summary

We report preliminary results for the $\psi(2S) \to AP$ decay branching ratios

- $Br(\psi(2S) \to b_1^+\pi^- \ + \ cc) = (7.3 \pm 1.9) \times 10^{-4}$;
- $Br(\psi(2S) \to K_1^+(1270)K^- \ + \ cc) = (7.6 \pm 1.7) \times 10^{-4}$; and
- $Br(\psi(2S) \to K_1^+(1400)K^- \ + \ cc) < 2.7 \times 10^{-4}$ 90% CL.

We find that AP decays are dominant exclusive hadron channels for the $\psi(2S)$. The discrepancy between the $K_1(1270)$ and $K_1(1400)$ rates is contrary to expectations based on flavor-SU(3).

We have made a first measurement of J/ψ decays to strange AP final states:

- $Br(J/\psi \to K_1^+(1270)K^- \ + \ cc) < 1.8 \times 10^{-3}$ 90% CL and
- $Br(J/\psi \to K_1^+(1400)K^- \ + \ cc) = (5.0 \pm 1.3) \times 10^{-3}$.

The $K_1(1270)\overline{K}$ channel is the first observation of an exclusive $\psi(2S)$ hadronic decay channel that is enhanced relative to the J/ψ in the context of the 14% rule. In addition, the flavor-SU(3)-violating $K_1(1270)$-$K_1(1400)$ asymmetry has an opposite character for the $\psi(2S)$ and J/ψ. This can not be accommodated by adjustments of the singlet-triplet mixing angle.

4 Acknowledgements

We acknowledge the strong efforts of the BEPC staff and the helpful assistance we received from the members of the IHEP computing center.

References

[1] L. Montanet *et al.* (Particle Data Group), Phys. Rev. **D50**, 1173 (1994).

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

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

[4] J.Z. Bai *et al.* (BES Collaboration), *Observation of New Anomalous Charmonium Decays*, paper submitted to the 1995 International Symposium on Lepton and Photon Interactions at High Energies, Beijing, China.

[5] See, for example, H.G. Blundell, S. Godfrey, and B. Phelps, Phys. Rev. **53**, 3712 (1996), M. Suzuki, Phys. Rev. **D47**, 1252 (1993), and references cited therein.

[6] J.Z. Bai *et al.* (BES Collaboration), *Branching Fractions for ψ' Decays to Octet-Baryon Pairs*, paper submitted to the 1995 International Symposium on Lepton and Photon Interactions at High Energies, Beijing, China.

[7] The PDG value for $Br(J/\psi \rightarrow b_1^{\pm}\pi^{\mp}$ is $(3.24 \pm 0.26) \times 10^{-3}$. As a check of our $\psi(2S)$ measurement, we applied the same procedures to J/ψ's from $\psi(2S) \rightarrow \pi^+\pi^- J/\psi$ cascade decays. Our result, $(3.4 \pm 0.7) \times 10^{-3}$ agrees well with the PDG value.

[8] 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 $K_1(1270)$ ($M_{K1} = 1.270$ GeV and $\Gamma_{K1} = 0.090$ GeV) with a p-wave ρ meson Breit Wigner with $M_\rho = 0.77$ GeV and $\Gamma_\rho = 0.150$ GeV.