RECENT $\psi\prime$ AND χ_c RESULTS FROM BES

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Recent results on $\psi\prime$ and χ_c decays from BES are presented, including: the branching fractions for $\psi\prime \to \tau^+\tau^-$, for $\psi\prime$ hadronic decays into vector-pseudoscalar and vector-tensor mesons, for J/ψ,$\psi\prime$ decays to strange-axialvector plus pseudoscalar mesons, for $\psi\prime$ decaying to baryon-antibaryon pairs; the total width of the χ_{c0}, and the branching fractions for χ_c decays to $\pi^+\pi^-$, K^+K^-, $p\bar{p}$ final states.

1 Introduction

From 1993 to 1995, the BES collaboration collected 3.6 million $\psi\prime$ events produced via e^+e^- annihilations at the BEPC collider using the BES detector [1]. With this larger sample of $\psi\prime$ events than any previous experiment, we are able to carry out a number of investigations of various $\psi\prime$ decay channels, and to study properties of other charmonium states, such as the J/ψ, χ_c, etc. In this talk I will concentrate on the results that are measured for the first time, or that represent substantial improvements in precision.

2 $\psi\prime$ decay measurements

2.1 Branching fraction for $\psi\prime \to \tau^+\tau^-$

We measure the branching fraction for $\psi\prime \to \tau^+\tau^-$ decay to be

$$B(\psi\prime \to \tau^+\tau^-) = (3.5 \pm 0.5 \pm 0.6) \times 10^{-3}.$$

The expectation for $e-\mu-\tau$ universality is $B_{ee} = B_{\mu\mu} = B_{\tau\tau}/0.3885$, where the effect of the limited available phase space for the $\tau^+\tau^-$ mode is included. Our measurement for $B_{\tau\tau}$, together with the PDG value of $B(\psi\prime \to e^+e^-) = (8.8 \pm 1.3) \times 10^{-3}$ and $B(\psi\prime \to \mu^+\mu^-) = (7.7 \pm 1.7) \times 10^{-3}$ [2], are in good agreement with $e-\mu-\tau$ universality.

2.2 Hadronic $\psi\prime$ decays

One major puzzle in hadronic ψ decays is the large discrepancy between the decay widths for $J/\psi \to \rho\pi$ and K^*K branching fractions and the corresponding widths for $\psi\prime$ decays. These modes are expected to proceed via $\psi\prime \to ggg$, with widths proporsional to the square of the $c\bar{c}$ wave function at the origin, which is well determined from dilepton decays. The perturbative QCD prediction, known as "the 15% rule," is

$$Q_h \equiv \frac{B(\psi\prime \to h)}{B(J/\psi \to h)} = \frac{B(\psi\prime \to ggg)}{B(J/\psi \to ggg)} = \frac{B(\psi\prime \to e^+e^-)}{B(J/\psi \to e^+e^-)} = (14.6 \pm 2.2)\%.$$

In 1983, the Mark II Collaboration [3] reported results for the ratios of branching fractions $Q_{\rho\pi} < 0.0063$, $Q_{K^*\overline{K}} < 0.011$, which badly violate the perturbative QCD expectation.

Recently BES has systematically studied hadronic $\psi\prime$ decays to VP, VT,AP,VS, TP, VV, $B\overline{B}$ final states, and has made substantial progress on the study of the charmonium hadronic decay.

Branching fractions of $\psi\prime$ decays to VP and VT mesons

We observed anomalous suppressions in VP and VT final states of $\psi\prime$ decays. The results are listed in Table 1. The following conclusions can be extracted:

1. We set new 90% CL upper limits for the $\rho\pi$ and $K^{*\pm}K^{\mp}$ decay modes which are significantly lower than the corresponding upper limits set by Mark II group [3]. The limits on the ratios of branching fractions,$Q_{\rho\pi} < 0.0023$ and $Q_{K^{*\pm}K^{\mp}} < 0.0064$, are more than factors of 60 and 20, respectively, below the PQCD predictions. This confirms the previous observation of VP suppression of $\psi\prime$ decays and shows that it persists at even higher levels of sensitivity.

2. The first measurement has been made for the branching fraction of the $\psi\prime$ decay to $K^{*0}\overline{K}^0 + c.c.$ final states (VP mode), which

yields the ratio of branching fractions of $Q_{K^{*0}K^0} = 0.020 \pm 0.007$.

3. There have been a number of theoretical attempts to explain the VP suppression puzzle [4-7], however, none of them can explain these BES results.

4. The branching fractions of ωf_2, ρa_2 and $K^{*0}\overline{K}_2^{*0} + c.c.$, vector-tensor final states, are measured in $\psi\prime$ decays for the first time. The corresponding ratios of branching fractions are much lower than the PQCD expectation. This changes the long-held view that the anomaly in charmonium hadronic decays is restricted to vector-pseudoscalar final states. Now the puzzle extends to the VT decay!

5. The discovery of an anomaly in VT decays is theoretically even more puzzling than that for VP decays. The strongly suppressed vector- pseudoscalar decays, i.e. $\rho\pi$, $K^{*\pm}K^{\mp}$ and $K^{*0}\overline{K}^0$ + $c.c.$, are not allowed by the PQCD expectation that total hadron helicity is conserved (HHC) in high-momentum-transfer exclusive processes [5]. A recent analysis [8] has shown that the vector-tensor decays, i,e, ωf_2, ρa_2 and $K^{*0}\overline{K}_2^{*0} + c.c.$, are allowed by HHC. Hence their suppression poses new challenges to the theory.

Table 1. Experimental Ratios of VP and VT modes

	Decay Mode	B($\psi\prime$) (10^{-5})	Q (%)
VP	$\rho\pi$	< 2.9	< 0.23
	$K^{*\pm}K^{\mp}$	< 3.2	< 0.64
	$K^{*0}\overline{K}^0 + c.c.$	8.4 ± 2.9	2.0 ± 0.7
VT	ωf_2	< 15	< 3.5
	ρa_2	31 ± 19	2.8 ± 1.7
	$K^{*0}\overline{K}_2^{*0} + c.c.$	< 18	< 2.8

note: Upper limits are at 90% confidence level.

J/ψ and $\psi\prime$ decays to strange-axialvector plus pseudoscalar mesons

Since the strange members of the two $^3P_1$ and $^1P_1$ octets, called the K_A and K_B, respectively, do not have definite C-parity, the observed physical states are mixtures of the K_A and K_B quark states. These are identified with the $K_1(1270)$ and the $K_1(1400)$ meson states:

$$K_1(1270) = cos\theta K_B + sin\theta K_A$$
$$K_1(1400) = cos\theta K_A - sin\theta K_B,$$

where the mixing angle is near $\theta = 45^\circ$ [9]. To the extent that flavor-SU(3) is a good symmetry, the amplitude for two body decays to conjugate mesons in the same pair of octets should be equal. Thus, since the $J/\psi(\psi') \to a_1\pi$ decays are forbidden by G-parity, the $J/\psi(\psi') \to K_A\overline{K}$ decays are disallowed and one expects relatively pure $K_B\overline{K}$ final states in J/ψ and ψ' decays. In that case, since

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

with $\theta \simeq 45^\circ$, there should be roughly equal amounts of $K_1(1270)$ and $K_1(1400)$.

Since there are no PDG entries for either the J/ψ or ψ' decays to $K_1\overline{K}$, we search for J/ψ and $\psi\prime \to K_1^+K^-$ decays where the K_1^+ decays via $K_1^+ \to K^+\pi^+\pi^-$:

$$K_1^+(1270) \to K^+\rho^0 \to K^+\pi^+\pi^-,$$
$$K_1^+(1270) \to K^{*0}\pi^+ \to K^+\pi^+\pi^-,$$
$$K_1^+(1400) \to K^{*0}\pi^+ \to K^+\pi^+\pi^-.$$

The J/ψ sample is produced by $\psi\prime \to \pi^+\pi^-J/\psi$ decay.

The preliminary results are listed on Table 2. The $K_1(1270)\overline{K}$ channel is the first observation of an exclusive $\psi\prime$ hadronic decay channel that is enhanced relative to the J/ψ in the context of the 15% rule. In addition, contrary to the flavor-SU(3) expectation of equal amounts of $K_1(1270)$ and $K_1(1400)$, a flavor-SU(3)-violating $K_1(1270) - K_1(1400)$ asymmetry is observed, and this asymmetry shows an opposite character for the J/ψ and $\psi\prime$. This can not be accommodated by adjustments of the singlet-triplet mixing angle.

Table 2: Branching Fractions of $J/\psi, \psi' \to K_1^+K^-$ Decays. (10^{-4})

	$K_1(1270)\overline{K}$	$K_1(1400)\overline{K}$
$\psi\prime$	$7.6 \pm 0.9 \pm 1.5$	<2.7
J/ψ	<18	$50 \pm 6 \pm 11$

note: Upper limits are at 90% confidence level.

Branching fractions of $\psi\prime$ decays to baryon pairs

The branching fractions for $\psi\prime \to B_i\overline{B}_i$, where $B_i = p, \Lambda, \Sigma^0, \Xi^-, \Delta^{++}, \Sigma^-(1385), \Xi^0(1530)$ and Ω^-, have been measured. The preliminary results are listed on Table 3, together with their ratios of branching fractions. The $\psi\prime \to p\overline{p}$ and $\Lambda\overline{\Lambda}$ results are in good agreement with 15% rule expectations. The rule works less well for the $\Xi^-\overline{\Xi^+}$, $\Sigma^0\overline{\Sigma^0}$, $\Delta^{++}\overline{\Delta^{--}}$, $\Sigma^{*-}\overline{\Sigma^{*+}}$ modes, which are somewhat below expectations. However, there are no dramatic suppressions as in the case of vector-pseudoscalar meson final states. We see no $\psi\prime \to \Xi^{*0}\overline{\Xi}^{*0}$ and $\Omega^-\overline{\Omega}^+$ events, and give 90% CL upper limits for these modes.

Table 3: Experimental ratios of $B\overline{B}$ modes

Decay Mode	B($\psi\prime$) (10^{-5})	Q (%)
$p\overline{p}$	32.9 ± 4.6	15.4 ± 2.2
$\Lambda\overline{\Lambda}$	20.3 ± 3.4	15.0 ± 2.5
$\Sigma^0\overline{\Sigma}^0$	11.7 ± 4.1	9.2 ± 3.2
$\Delta^{++}\overline{\Delta}^{--}$	8.8 ± 3.4	8.0 ± 3.0
$\Xi^-\overline{\Xi}^+$	10.3 ± 3.7	11.4 ± 4.1
$\Sigma^{*-}\overline{\Sigma}^{*+}$	4.6 ± 4.8	4.5 ± 4.7
$\Xi^{*0}\overline{\Xi}^{*0}$	< 7.2	
$\Omega^-\overline{\Omega}^+$	< 7.1	

In the context of flavor SU(3), a pure $c\overline{c}$ state is a flavor singlet and, in the limit of SU(3) flavor symmetry, the phase-space-corrected reduced branching fractions to any baryon octet pair, $| M_i |^2$,

$$| M_i |^2 = \frac{B(\psi\prime \to B_i\overline{B_i})}{\pi p^*/\sqrt{s}}$$

(p^* is the momentum of the baryon in the $\psi\prime$ rest frame), should be the same for every octet baryon,B_i. Deviations from this rule would indicate non- SU(3) singlet contributions to the decay amplitude. In Fig. 1, we plot the reduced branching fractions derived from our measurements for $\psi\prime \to B_8\overline{B_8}$. The data are inconsistent with strict flavor-SU(3) (χ^2/dof=15.0/3). Fitting the data with a simple SU(3)-violating model [10] results in an octet decay amplitude that $\sim 22\%$ that of the singlet amplitude, significantly larger than the $\sim 8\%$ octet amplitudes that come from similar fits to the corresponding J/ψ reduced branching fractions.

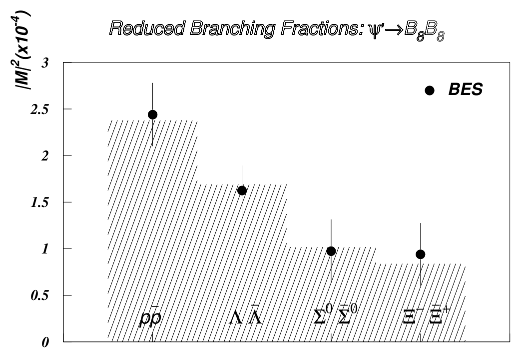

Figure 1: The reduced branching fractions $|M_i|^2$ for $\psi' \to B_8\overline{B_8}$ decays. The shaded bars indicate results of a fit to an SU(3)-symmetry breaking model with an antisymmetric-octet amplitude that is $\sim 22\%$ of the SU(3)-conserving singlet term.

3 The measurements of χ_c decay widths

Using the full BES $\psi\prime$ event sample, we subject $\gamma\pi^+\pi^-$ and γK^+K^- candidate events to a four-constraint kinematic fit. The resulting $\pi^+\pi^-$ and K^+K^- invariant mass spectra show clear peaks corresponding to χ_{c0} and χ_{c2}, respectively. Since parity conservation forbids χ_{c1} and $\eta_c\prime$ decays to these final states, there is no distortion of the χ_{c0} and χ_{c2} spectra due to contaminations from these resonances.

A Monte Carlo simulation is used to determine the detection efficiencies for $\gamma\pi^+\pi^-$ and γK^+K^- channels and the probabilities for cross contamination betweem them. Our experimental mass resolution is calibrated by fitting the χ_{c2} to a convolution of a gaussian reslolution function and a Breit-Wigner resonance line with the PDG value for the χ_{c2} total width, which has been precisely determined by the E760 experiment [11]. After these correction, fits to the $\chi_{c0} \to \pi^+\pi^-$ and K^+K^- invariant mass spectra yield the following results:

$$\Gamma_{\chi_{c0}} = 15.0 \pm^{3.2}_{2.8} \, MeV,$$

where the error includes both statistical and systematic uncertainties. This result is in agreement with the world average value (14 ± 5 MeV) [2], but with higher precision. It agrees with Kwong's theoretical prediction (14.8 ± 1.9 MeV) [12], while it has large discrepancy with the calculation by G.T.Bodwin (4.8 ± 0.7 MeV) [13].

We have also obtained the partial widths of χ_{c0}, χ_{c2} decays to $\pi^+\pi^-$, K^+K^- and $p\overline{p}$ listed in

Table 4. It can be seen that the BES measurements are more precise than PDG values with the only exception of $\chi_{c2} \to p\overline{p}$. For partial widths of $\chi_{c0} \to \pi^+\pi^-, K^+K^-$, BES measurements deviate from PDG values significantly, while for other partial widths they coincide within one standard deviation. From the data in Table 4, we obtained following ratios:

$$\frac{B(\chi_{c0} \to \pi^+\pi^-)}{B(\chi_{c0} \to K^+K^-)} = 1.24 \pm 0.13,$$
$$\frac{B(\chi_{c2} \to \pi^+\pi^-)}{B(\chi_{c2} \to K^+K^-)} = 2.95 \pm 1.18,$$
$$\frac{B(\chi_{c0} \to \pi^+\pi^-)}{B(\chi_{c2} \to \pi^+\pi^-)} = 2.81 \pm 0.63,$$
$$\frac{B(\chi_{c0} \to K^+K^-)}{B(\chi_{c2} \to K^+K^-)} = 6.6 \pm 2.7.$$

Table 4: Partial Widths for χ_{c0}, χ_{c2} Decays to $\pi^+\pi^-$, K^+K^- and $p\overline{p}$ (10^{-4})

		χ_{c0}	χ_{c2}
BES	$\pi^+\pi^-$	42.7 ± 6.4	15.2 ± 3.4
	K^+K^-	34.4 ± 5.1	5.2 ± 2.1
	$p\overline{p}$	1.45 ± 0.50	0.96 ± 0.54
PDG	$\pi^+\pi^-$	75 ± 21	19 ± 10
	K^+K^-	71 ± 24	15 ± 11
	$p\overline{p}$	< 9.0	1.00 ± 0.10

4 Summary

With the 3.6M $\psi\prime$ event sample, BES is able to study its decay properties with improved precision and to extend the investigation to J/ψ and χ_c. Significant improvements have been reached in many decay channels measurements.

1. The branching fraction of $\psi\prime \to \tau^+\tau^-$ has been determined for the first time.
2. Severe suppression is observed in $\psi\prime$ decays into vector plus pseudoscalar mesons, $\rho\pi$, $K^{*\pm}\overline{K}^{\mp}$, and $K^{*0}\overline{K}^0 + c.c.$.
3. Sgnificant suppression is seen for the first time in $\psi\prime$ decays into the vector plus tensor meson final states ωf_2, ρa_2 and $K^{*0}\overline{K}_2^{*0} + c.c.$.
4. Existing theoretical models can not explain these VP, VT suppressions.
5. For the strange AP final states, a flavor-SU(3)-violating $K_1(1270) - K_1(1400)$ asymmetry is observed and has an opposite character for the J/ψ and $\psi\prime$.
6. The 15% rule is basically followed for the $\psi\prime$ decays to baryon-antibaryon pairs.
7. The total decay width for χ_{c0} and the patial decay widths of $\pi^+\pi^-$, K^+K^- and $p\overline{p}$ for χ_{c0} and χ_{c2} have been measured with improved accuracies.

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