Experimental charmonium decay results from BES

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Based on 14 million $\psi(2S)$ and 58 million J/ψ events collected by the BESII detector, the leptonic decay of $\psi(2S)$ into $\tau^+\tau^-$, $\psi(2S)$ multi-body decays, χ_{cJ} decays, and J/ψ hadronic decays are studied, and the branching fractions of these decays are reported. These results may shed light on the understanding of QCD.

I. INTRODUCTION

The Beijing spectrometer (BES) is a general purpose solenoidal detector at the Beijing Electron Positron Collider (BEPC) storage ring, which operates at center-of-mass energies from 2 to 5 GeV. The BES detector (BESII) is described in Ref. [1].

In this paper, we focus on studies of the $\psi(2S)$ leptonic decay, $\psi(2S)$ radiative decays, $\psi(2S)$ hadronic decays, χ_{cJ} decays, and J/ψ decays based on 14 million $\psi(2S)$ and 58 million J/ψ events collected by the BESII detector.

II. $\psi(2S)$ DECAYS

A. $\psi(2S) \to \tau\tau$

The $\psi(2S)$ provides an opportunity to compare the three lepton generations by studying the leptonic decays $\psi(2S) \to e^+e^-$, $\mu^+\mu^-$, and $\tau^+\tau^-$. The leptonic decay widths are approximately described by the relation $B_{ee} \simeq B_{\mu\mu} \simeq B_{\tau\tau}/0.3885$, which is in good agreement with the BESI $B_{\tau\tau}$ measurement [2]. Based on 14 million $\psi(2S)$ events, the branching fraction for $\psi(2S) \to \tau^+\tau^-$ is remeasured [3]. The $\tau^+\tau^-$ pairs are reconstructed from $\tau^+\tau^- \to \mu^+\bar{\nu}_\tau\nu_\mu e^-\nu_\tau\bar{\nu}_e$ and $\tau^+\tau^- \to e^+\bar{\nu}_\tau\nu_e\mu^-\nu_\tau\bar{\nu}_\mu$. At the $\psi(2S)$ resonance, 1015 signal events are observed, while 516 events are estimated to be from $e^+ + e^- \to \tau^+\tau^-$, determined using a data sample taken at $\sqrt{s} = 3.65$ GeV. The branching fraction is calculated to be $(0.310 \pm 0.021 \pm 0.038)\%$, where the first error is statistical and the second is systematic. Compared with the BESI result, the number of events is much bigger and the QED contribution and the efficiency and background estimations are improved.

B. Radiative decays

Besides the conventional meson and baryon states, QCD also predicts a rich spectrum of glueballs, meson hybrids, and multi-quark states in the 1.0 to 2.5 GeV/c^2 mass region. Therefore, searches for evidence of these exotic states play an important role to test QCD. Such studies of these states have been performed in J/ψ radiative decays for a long time [4, 5], while studies in $\psi(2S)$ radiative decays have been limited due to low statistics in previous experiments [5, 6]. The radiative decays of $\psi(2S)$ to hadrons are expected to contribute about 1% to the total $\psi(2S)$ decay width [7]. However, the measured channels only sum up to about 0.05% [6].

Recently BESII measured the decays of $\psi(2S)$ into $\gamma p\bar{p}$, $\gamma 2(\pi^+\pi^-)$, $\gamma K^0_S K^+\pi^- + c.c.$, $\gamma K^+K^-\pi^+\pi^-$, $\gamma K^{*0}K^-\pi^+ + c.c.$, $\gamma K^{*0}\bar{K}^{*0}$, $\gamma\pi^+\pi^- p\bar{p}$, $\gamma 2(K^+K^-)$, $\gamma 3(\pi^+\pi^-)$, and $\gamma 2(\pi^+\pi^-)K^+K^-$, with the invariant mass of the hadrons (m_{hs}) less than 2.9 GeV/c^2 for each decay mode [8]. The differential branching fractions are shown in Fig. 1. In the mass distribution of $m_{p\bar{p}}$ for $\psi(2S) \to \gamma p\bar{p}$, although there is some excess of events near $p\bar{p}$ threshold as shown in Fig. 1(a), no significant narrow structure due to the $X(1859)$, observed in $J/\psi \to \gamma p\bar{p}$, is seen. The upper limit on the branching fraction is measured to be $\mathcal{B}[\psi(2S) \to \gamma X(1859) \to \gamma p\bar{p}] < 5.4 \times 10^{-6}$ at the 90% C.L. There is a wide peak in the $m_{2(\pi^+\pi^-)}$ distribution located at $1.4 \sim 2.2$ GeV/c^2, but its structure can not be resolved due to the low statistics. No obvious structure is observed in the other final states. The branching fractions below $m_{hs} < 2.9$ GeV/c^2 are given in Table I, and they sum up to 0.26% of the total $\psi(2S)$ decay width. This indicates that a larger data sample is needed to search for more decay modes and to resolve the substructure of $\psi(2S)$ radiative decays.

C. Hadronic decays

In perturbative QCD (pQCD), hadronic decays of both $\psi(2S)$ and J/ψ proceed dominantly via the annihilation of $c\bar{c}$ quarks into three gluons or one photon, followed by a hadronization process. This yields the so-called pQCD "12% rule", *i.e.*

$$Q_h \equiv \frac{B_{\psi' \to h}}{B_{J/\psi \to h}} = \frac{B_{\psi' \to ee}}{B_{J/\psi \to ee}} \simeq 12\%.$$

A large violation of this rule was firstly observed in decays to $\rho\pi$ and $K^*K + c.c.$ by Mark II [9], known as *the $\rho\pi$ puzzle*. Since then there have been many more measurements of $\psi(2S)$ decays by BES and recently

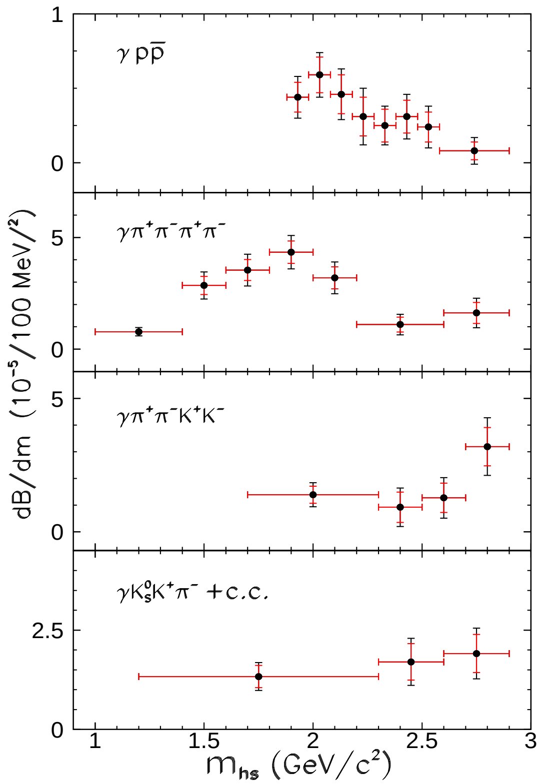

FIG. 1: Differential branching fractions for $\psi(2S)$ decays into $\gamma p\bar{p}$, $\gamma 2(\pi^+\pi^-)$, $\gamma K^+K^-\pi^+\pi^-$, and $\gamma K_S^0K^+\pi^-+c.c.$. Here m_{hs} is the invariant mass of the hadrons in each final state. For each point, the smaller longitudinal error is the statistical error, while the bigger one is the sum of statistical and systematic errors.

by the CLEO collaboration for the study of the 12% rule. Table II summarizes recent measurements on $\psi(2S)$ decays by BES. For the $\psi(2S)$ decays listed, the Q_h ratios are in agreement with the 12% rule within $1 \sim 2\sigma$, except for the obviously suppressed channel $\psi(2S) \to \omega f_2(1270)$.

The branching fractions of $\psi(2S)$ decays into octet baryons have also been measured; the results are listed in Table II. They are in agreement with the results published by the CLEO collaboration within 2σ for $p\overline{p}$ and within 1σ for the $\Lambda\bar{\Lambda}$, $\Sigma^0\bar{\Sigma}^0$, and $\Xi^-\Xi^+$ channels. For $\psi(2S) \to N\bar{N}\pi$, the ratios of the measured branching fractions of the $p\overline{p}\pi^0$ isospin partners are given by $\mathcal{B}(\psi(2S) \to p\overline{p}\pi^0) : \mathcal{B}(\psi(2S) \to p\bar{n}\pi^-) : \mathcal{B}(\psi(2S) \to \bar{p}p\pi^+) = 1 : 1.86 \pm 0.27 : 1.91 \pm 0.27$, which is consistent with the isospin symmetry prediction $1 : 2 : 2$.

TABLE I: Branching fractions for $\psi(2S) \to \gamma + hadrons$ with $m_{hs} < 2.9$ GeV/c^2, where the upper limits are determined at the 90% C.L. [8].

Mode	$\mathcal{B}(\times 10^{-5})$
$\gamma p\bar{p}$	2.9±0.4±0.4
$\gamma 2(\pi^+\pi^-)$	39.6±2.8±5.0
$\gamma K_S^0K^+\pi^- + c.c.$	25.6±3.6±3.6
$\gamma K^+K^-\pi^+\pi^-$	19.1±2.7±4.3
$\gamma K^{*0}K^+\pi^- + c.c.$	37.0±6.1±7.2
$\gamma K^{*0}\bar{K}^{*0}$	$24.0 \pm 4.5 \pm 5.0$
$\gamma\pi^+\pi^-p\bar{p}$	2.8±1.2±0.7
$\gamma K^+K^-K^+K^-$	< 4
$\gamma 3(\pi^+\pi^-)$	< 17
$\gamma 2(\pi^+\pi^-)K^+K^-$	< 22

TABLE II: Branching fractions for $\psi(2S)$ hadronic decays. Here the ratio Q_h is defined as $Q_h = \frac{\mathcal{B}(\psi(2S)\to h)}{\mathcal{B}(J/\psi\to h)}$, where the $\mathcal{B}(J/\psi \to h)$ values are taken from Ref. [6].

Mode: h	$\mathcal{B}(\times 10^{-4})$	$Q_h(\%)$
$p\overline{p}$	$3.36 \pm 0.09 \pm 0.25$	14.9 ± 1.4
$\Lambda\bar{\Lambda}$	$3.39 \pm 0.20 \pm 0.32$	16.7 ± 2.1
$\Sigma^0\bar{\Sigma}^0$	$2.35 \pm 0.36 \pm 0.32$	16.8 ± 3.6
$\Xi^-\Xi^+$	$3.03 \pm 0.40 \pm 0.32$	16.8 ± 4.7
$p\bar{n}\pi^-$	$2.45 \pm 0.11 \pm 0.21$	12.0 ± 1.5
$\bar{p}n\pi^+$	$2.52 \pm 0.12 \pm 0.22$	12.9 ± 1.7
$\pi^0 2(\pi^+\pi^-)$	$24.9 \pm 0.7 \pm 3.6$	10.5 ± 2.0
$\omega\pi^+\pi^-$	$8.4 \pm 0.5 \pm 1.2$	11.7 ± 2.4
$\omega f_2(1270)$	$2.3 \pm 0.5 \pm 0.4$	5.4 ± 0.6
$b_1^\pm\pi^\mp$	$5.1 \pm 0.6 \pm 0.8$	17.0 ± 4.2
$\pi^0 2(\pi^+\pi^-)K^+K^-$	$10.0 \pm 2.5 \pm 1.8$	—

III. χ_{cJ} DECAYS

A. $\chi_{cJ} \to \phi\phi$

Decays of $\chi_{cJ} \to K^+K^-K^+K^-$ are measured using 14 million $\psi(2S)$ decays [10]. The branching fractions including intermediate states are given in Table III. The decay $\chi_{cJ} \to \phi K^+K^-$ is observed for the first time, and the precision of the measurements $\chi_{cJ} \to \phi\phi$ and $K^+K^-K^+K^-$ are improved compared with PDG values.

The branching fractions of $\chi_{cJ} \to \phi\phi$ together with previous BES measurements on $\chi_{cJ} \to \omega\omega$ [12] and $\chi_{cJ} \to K^*(892)\bar{K}^*(892)$ [13] are used to predict the decay branching fractions of χ_{cJ} to other vector meson pairs, like $\rho\rho$ and $\omega\phi$ [14], where a large double OZI suppressed amplitude is expected.

TABLE III: Summary of χ_{cJ} hadronic decays. Upper limits are given at the 90% C.L. For $\chi_{cJ} \to K^0_S K^+\pi^- + c.c.$ and $\eta\pi^+\pi^-$, branching fractions of $\mathrm{Br}(\psi' \to \gamma\chi_{c0}) = (8.6 \pm 0.7)\%$, $\mathrm{Br}(\psi' \to \gamma\chi_{c1}) = (8.4 \pm 0.8)\%$, and $\mathrm{Br}(\psi' \to \gamma\chi_{c2}) = (6.4 \pm 0.6)\%$ are used in the calculation. For other decays, branching fractions of $\mathrm{Br}(\psi(2S) \to \gamma\chi_{cJ})$ from CLEOc [11] are used.

Decay mode X	$\mathrm{Br}(\chi_{c0} \to X)$ $(\times 10^{-3})$	$\mathrm{Br}(\chi_{c1} \to X)$ $(\times 10^{-3})$	$\mathrm{Br}(\chi_{c2} \to X)$ $(\times 10^{-3})$
$2(K^+K^-)$	$3.48 \pm 0.23 \pm 0.47$	$0.70 \pm 0.13 \pm 0.10$	$2.17 \pm 0.20 \pm 0.31$
ϕK^+K^-	$1.03 \pm 0.22 \pm 0.15$	$0.46 \pm 0.16 \pm 0.06$	$1.67 \pm 0.26 \pm 0.24$
$\phi\phi$	$0.94 \pm 0.21 \pm 0.13$	—	$1.70 \pm 0.30 \pm 0.25$
$K^0_S K^+\pi^- + c.c.$	< 0.35	$4.0 \pm 0.3 \pm 0.5$	$0.8 \pm 0.3 \pm 0.1$
$\eta\pi^+\pi^-$	< 1.1	$5.9 \pm 0.7 \pm 0.8$	< 1.7

B. $\chi_{cJ} \to K^0_S K\pi, \eta\pi\pi$

Decays of χ_{c0} and χ_{c2} into three pseudo-scalars are highly suppressed by the spin-parity selection rule. BES measured the branching fractions of χ_{c1} decays into $K^0_S K^+\pi^- + c.c.$ and $\eta\pi^+\pi^-$, including the intermediate states involved [15]. The branching fractions or upper limits at the 90% C.L. are summarized in Table III.

The $K^0_S K^+\pi^- + c.c.$ events are mainly produced via $K^*(892)$ intermediate states, and the $\eta\pi^+\pi^-$ events via $f_2(1270)\eta$ or $a_0(980)\pi$. The branching fractions [15] for these resonances are

$$\begin{aligned} &\mathrm{Br}(\chi_{c1} \to K^*(892)^0\bar{K}^0 + c.c.) \\ &\qquad = (1.1 \pm 0.4 \pm 0.2) \times 10^{-3}, \\ &\mathrm{Br}(\chi_{c1} \to K^*(892)^+K^- + c.c.) \\ &\qquad = (1.6 \pm 0.7 \pm 0.3) \times 10^{-3}, \\ &\mathrm{Br}(\chi_{c1} \to f_2(1270)\eta) \\ &\qquad = (3.0 \pm 0.7 \pm 0.5) \times 10^{-3}, \\ &\mathrm{Br}(\chi_{c1} \to a_0(980)^+\pi^- + c.c. \to \eta\pi^+\pi^-) \\ &\qquad = (2.0 \pm 0.5 \pm 0.5) \times 10^{-3}. \end{aligned}$$

Except for $\chi_{c1} \to K^0_S K^+\pi^- + c.c.$, all other modes are first observations.

IV. $J/\psi \to \Lambda\bar{\Lambda}\pi^0$, $\Lambda\bar{\Lambda}\eta$

The isospin violating process $J/\psi \to \Lambda\bar{\Lambda}\pi^0$ has been studied by the DM2 [16] and BESI [17] collaborations, and its average branching fraction is quoted as $\mathcal{B}(J/\psi \to \Lambda\bar{\Lambda}\pi^0) = (2.2 \pm 0.6) \times 10^{-4}$ [6]. However, the isospin conserving process $J/\psi \to \Lambda\bar{\Lambda}\eta$ has not been reported. Is it true that $\mathcal{B}(J/\psi \to \Lambda\bar{\Lambda}\pi^0) > \mathcal{B}(J/\psi \to \Lambda\bar{\Lambda}\eta)$? BESII used 58 million J/ψ events to study $J/\psi \to \Lambda\bar{\Lambda}\pi^0$ [18]. It is found that this decay is seriously contaminated by $J/\psi \to \Sigma^0\pi^0\bar{\Lambda} + c.c.$ and $\Sigma^+\pi^-\bar{\Lambda} + c.c.$ decays. For estimating these backgrounds, the branching fraction of $J/\psi \to \Sigma^+\pi^-\bar{\Lambda} + c.c.$ was measured and determined to be to be $(15.2 \pm 0.8 \pm 1.6) \times 10^{-4}$. Assuming isospin symmetry between this and the neutral decay mode and after subtracting these backgrounds, no significant signal is observed for $J/\psi \to \Lambda\bar{\Lambda}\pi^0$, and the upper limit is determined to be $\mathcal{B}(J/\psi \to \Lambda\bar{\Lambda}\pi^0) < 0.64 \times 10^{-4}$ at the 90% C.L. A clear signal is seen for $J/\psi \to \Lambda\bar{\Lambda}\eta$ and the branching fraction is determined to be $(2.62 \pm 0.60 \pm 0.44) \times 10^{-4}$. This indicates that the $J/\psi \to \Lambda\bar{\Lambda}\pi^0$ is suppressed due to isospin conservation violation.

V. SUMMARY

Using the 14 million $\psi(2S)$ and 58 million J/ψ events taken with BESII detector at the BEPC storage ring, BES Collaboration has provided many interesting results on charmonium decays, including the observation of many $\psi(2S)$ radiative decays, some $\psi(2S)$ hadronic decays, χ_{cJ} decays, and determined that the isospin violating process $J/\psi \to \Lambda\bar{\Lambda}\pi^0$ is suppressed.

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