Recent Results of $\psi(2S)$ Decays from BES

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Results of many $\psi(2S)$ hadronic decays and the results of $\psi(2S)$ radiative/hadronic transitions from BES collaboration in the past year are presented. Measurement of $B(J/\psi \rightarrow K_S^0 K^0_L)$ and the preliminary result of searching for the decay $\psi(3770) \rightarrow \rho \pi$ are also reported.

Keywords: charmonium; hadron; transition.

1. Introduction

The Beijing Spectrometer (BES) is a general purpose solenoidal detector running at the Beijing Electron-Positron Collider (BEPC) storage ring. BEPC operates in the center of mass energy range from 2 to 5 GeV with a luminosity at the $\psi(2S)$ energy of approximately $1 \times 10^{31}$ cm$^{-2}$s$^{-1}$. The numbers/luminosities of $\psi(2S)$, $J/\psi$, $\psi(3770)$ and the continuum events ($\sqrt{s} = 3.65$ GeV) taken with the BES detector, are listed in Table 1. BES (BESI) is described in detail in Ref. 1 and the upgraded BES detector (BESII) is described in Ref. 2.

| Detector config. | BESH   | BESH | BESI  |
|------------------|--------|------|-------|
| $E_{cm}$ (GeV)    | 3.686  | 3.097| 3.773 |
| Total. Num. (milon) | $14.0 \pm 0.6$ | $57.7 \pm 2.7$ | $17.3 \pm 0.5$ |
| or Int. $\mathcal{L}$ (pb$^{-1}$) | $3.79 \pm 0.31$ | $6.42 \pm 0.24$ |

2. Results of $\psi(2S)$ hadronic final state decays

From perturbative QCD (pQCD), it is expected that both $J/\psi$ and $\psi(2S)$ decaying into light hadrons are dominated by the annihilation of $c\bar{c}$ into three gluons or one virtual photon, with a width proportional to the square of the wave function at the
origin cite. This yields the pQCD “12% rule”,
\[ Q_h = \frac{B_{\psi \rightarrow h}}{B_{J/\psi \rightarrow h}} = \frac{B_{\psi \rightarrow e^+e^-}}{B_{J/\psi \rightarrow e^+e^-}} \approx 12\%. \quad (1) \]

In order to test the above rule, systematic studies of \( \psi(2S) \) exclusive hadronic decays have been carried out at the BES. Table 2 summarizes the results of branching fraction measurements for all decays modes of the \( \psi(2S) \) studied. The table includes the data for the corresponding \( J/\psi \) decays as well as the ratios of branching fractions of the \( \psi(2S) \) to the \( J/\psi \). Some interesting features are found: At BES, a Partial Wave Analysis (PWA) is carried out for the \( \pi^+\pi^-\pi^0 \) final state using the helicity amplitude method. \( \psi(2S) \rightarrow \rho(770)\pi \) is observed. In the \( \pi\pi \) mass spectrum, a high mass enhancement with mass round 2.15 GeV is observed, seen in Figure 1. Attributing this enhancement to the \( \rho(2150) \) resonance, the branching fraction is measured to be \( B(\psi \rightarrow \rho(2150)\pi \rightarrow \pi^+\pi^-\pi^0) = (19.4 \pm 2.5^{+11.5}_{-3.4}) \times 10^{-5} \). The ratio \( B(\psi(2S) \rightarrow K^{*+}K^{-+}c.c.)\) from BES shows a large isospin violation between the charged and neutral modes of \( \psi(2S) \rightarrow K^*(892)\bar{K} + c.c. \) decays; Compared with \( J/\psi \rightarrow K^0_LK^0_L \) \( \psi(2S) \rightarrow K^0_SK^0_L \) is enhanced relative to the “12% rule”. More details on these analyses may be found in Refs. 3 and 4.

| Mode     | Channel  | \( B(\psi(2S)) \) (\( \times 10^{-6} \)) | \( B(J/\psi) \) (\( \times 10^{-6} \)) \( \rho \) | \( Q_h \) (%) |
|----------|----------|---------------------------------|---------------------------------|-------------|
| \( \rho\pi \) | 5.1 \( \pm 0.7 \) \( \pm 1.1 \) | 127 \( \pm 9 \) | 0.40 \( \pm 0.11 \) |
| \( K^{*+}K^{-+} + c.c. \) | 2.9 \( \pm 1.7 \) \( \pm 0.4 \) | 50 \( \pm 4 \) | 0.59 \( \pm 0.36 \) |
| \( K^{*0}K^0 + c.c. \) | 13.3 \( \pm 2.8 \) \( \pm 1.7 \) | 42 \( \pm 4 \) | 2.32 \( \pm 0.8 \) |
| \( \phi\pi^0 \) | < 0.41 | < 0.068 | – |
| \( \phi\eta \) | 3.3 \( \pm 1.1 \) \( \pm 0.5 \) | 6.5 \( \pm 0.7 \) | 5.1 \( \pm 1.9 \) |
| \( \omega\eta \) | 2.8 \( \pm 1.5 \) \( \pm 0.6 \) | 3.3 \( \pm 0.4 \) | 8.5 \( \pm 5.0 \) |
| \( \omega\eta' \) | < 3.2 | 15.8 \( \pm 1.6 \) | < 2.0 |
| \( \omega\eta'' \) | 3.1 \( \pm 2.5 \) \( \pm 0.7 \) | 1.67 \( \pm 0.25 \) | 19 \( \pm 15 \) |
| \( \omega\pi^0 \) | 1.87 \( \pm 0.62 \) \( \pm 0.28 \) | 4.2 \( \pm 0.6 \) | 4.4 \( \pm 1.8 \) |
| \( \rho\eta \) | 1.78 \( \pm 0.64 \) \( \pm 0.17 \) | 1.93 \( \pm 0.23 \) | 9.2 \( \pm 0.9 \) |
| \( \rho\eta' \) | 1.87 \( \pm 1.64 \) \( \pm 0.33 \) | 1.05 \( \pm 0.18 \) | 17.8 \( \pm 11.9 \) |
| \( K^0_SK^0_L \) | 5.24 \( \pm 0.47 \) \( \pm 0.48 \) | 18.2 \( \pm 1.4 \) | 28.8 \( \pm 3.7 \) |
| \( \pi^+\pi^-\pi^0 \) | 18.1 \( \pm 1.8 \) \( \pm 1.9 \) | 210 \( \pm 12 \) | 0.86 \( \pm 0.13 \) |
| \( pp\pi^0 \) | 13.2 \( \pm 1.0 \) \( \pm 1.5 \) | 10.9 \( \pm 0.09 \) | 12.1 \( \pm 1.9 \) |
| \( p\eta \) | 5.8 \( \pm 1.1 \) \( \pm 0.7 \) | 2.09 \( \pm 0.18 \) | 2.8 \( \pm 0.7 \) |
| \( 3(\pi^+\pi^-) \) | 54.5 \( \pm 4.2 \) \( \pm 8.7 \) | 40 \( \pm 20 \) | 14 \( \pm 8 \) |

BES also searches for the Non-\( D\bar{D} \) decay of \( \psi(3770) \rightarrow \rho\pi \) using a data sample of \( (17.3 \pm 0.5) pb^{-1} \) taken at the center-of-mass energy of 3.773 GeV. No \( \rho\pi \) signal is observed, and the upper limit of the cross section is measured to be \( \sigma(e^+e^- \rightarrow \rho\pi) < 6.0 \, pb \) at 90% C. L. Considering the interference between the continuum amplitude and the \( \psi(3770) \) resonance amplitude, the branching fraction of \( \psi(3770) \) decays to \( \rho\pi \) is determined to be \( B(\psi(3770) \rightarrow \rho\pi) \in (6.0 \times 10^{-6}, 2.4 \times 10^{-3}) \) at
90\% C. L., as shown in Figure 2. This is in agreement with the prediction of the $S$- and $D$-wave mixing scheme of the charmonium states for solving the “$\rho \pi$ puzzle” between $J/\psi$ and $\psi^*(2S)$ decays [8,9].

![Fig. 1. Comparison between data (dots with error bars) and the final fit (solid histograms) in $\psi^*(2S) \rightarrow \pi^+\pi^-\pi^0$ PWA. (a) two pion invariant mass, with a solid line for the $\rho(770)\pi$, a dashed line for the $\rho(2150)\pi$, and a hatched histogram for background; (b) the $\rho$ polar angle in the $\psi^*(2S)$ rest frame; and (c) and (d) for the polar and azimuthal angles of the designated $\pi$ in $\rho$ helicity frame.]

Fig. 2. Restriction on $B(\psi^*(3770) \rightarrow \rho\pi)$ and $\phi$, the relative phase between $\psi^*(3770)$ strong and electromagnetic decay amplitudes, from the measurement of $\rho\pi$ at the $\psi^*(3770)$ peak in this experiment. The hatched area indicate the physical region at 90\% C. L.

3. Results of $\psi(2S)$ radiative and hadronic transitions

We report on the analysis of $\psi(2S) \rightarrow \pi^0J/\psi$, $\eta J/\psi$, and $\gamma\chi_{c1,2}$ decays based on a sample of $1.4 \times 10^8 \psi(2S)$ events collected with the BESII detector. Here $J/\psi$ is reconstructed by $e^+e^-$ or $\mu^+\mu^-$. Another analysis, based on a sample of approximately $4 \times 10^6 \psi(2S)$ events obtained with the BESI detector, is used for measuring branching fractions for the inclusive decay $\psi(2S) \rightarrow$ anything $J/\psi$, and the exclusive processes for the cases where $X = \eta$ and $X = \pi\pi$, as well as the cascade processes $\psi(2S) \rightarrow \gamma\chi_{c1/2} \rightarrow \gamma\gamma J/\psi$. The branching fractions and the ratios of the branching fractions are shown in Tables 3 and 4 along with the PDG value [5]. Details on these analyses may be found in Refs. 10 and 11.

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Table 3. Results from $\psi(2S) \to \gamma\gamma J/\psi$ (BESII data).

| Channel | $\pi^0/J/\psi$ | $\eta/J/\psi$ |
|---------|----------------|---------------|
| PDG (%) | 0.143 ± 0.014 ± 0.013 | 2.98 ± 0.09 ± 0.23 |
| Channel | $\gamma\chi_c$ | $\gamma\chi_{c2}$ |
| PDG (%) | 2.45 ± 0.22 | 3.16 ± 0.12 |

Table 4. Branching ratios and branching fractions (BESI data). PDG04-exp results are single measurements or averages of measurements, while PDG04-fit are results of their global fit to many experimental measurements. The BES results in the second half of the table are calculated using the PDG04 value of $B_{\pi\pi} = B(\psi(2S) \to J/\psi\pi^+\pi^-) = (31.7 \pm 1.1\%)$.

| Case | This exp. | PDG04-exp | PDG04-fit |
|------|-----------|-----------|-----------|
| $B(J/\psi(\text{anything}))/B_{\pi\pi}$ | 1.867 ± 0.026 ± 0.055 | 2.016 ± 0.150 | 1.821 ± 0.036 |
| $B(J/\psi\pi^0\pi^0)/B_{\pi\pi}$ | 0.570 ± 0.009 ± 0.026 | - | 0.59 ± 0.05 |
| $B(J/\psi\eta)/B_{\pi\pi}$ | 0.998 ± 0.005 ± 0.010 | 0.091 ± 0.021 | 0.100 ± 0.008 |
| $B(\gamma\chi_{c1})B(\chi_{c1} \to \gamma J/\psi)/B_{\pi\pi}$ | 0.126 ± 0.003 ± 0.038 | 0.085 ± 0.021 | 0.084 ± 0.006 |
| $B(\gamma\chi_{c2})B(\chi_{c2} \to \gamma J/\psi)/B_{\pi\pi}$ | 0.060 ± 0.000 ± 0.028 | 0.039 ± 0.012 | 0.041 ± 0.003 |
| $B(J/\psi(\text{anything}))$ (%) | 59.2 ± 0.8 ± 2.7 | 55 ± 7 | 57.6 ± 2.0 |
| $B(J/\psi\pi^0\pi^0)$ (%) | 18.1 ± 0.3 ± 1.0 | - | 18.8 ± 1.2 |
| $B(J/\psi\eta)$ (%) | 3.11 ± 0.17 ± 0.31 | 2.9 ± 0.5 | 3.16 ± 0.22 |
| $B(\gamma\chi_{c1})B(\chi_{c1} \to \gamma J/\psi)$ (%) | 4.0 ± 0.1 ± 1.2 | 2.66 ± 0.16 | 2.67 ± 0.15 |
| $B(\gamma\chi_{c2})B(\chi_{c2} \to \gamma J/\psi)$ (%) | 1.91 ± 0.01 ± 0.86 | 1.20 ± 0.13 | 1.30 ± 0.08 |

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