Recent physics results at BES

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Using 58M J/ψ, 14M $\psi(2S)$ and 33 pb^{-1} ψ'' events collected at BES-II detector, some charm physics results are obtained. In J/ψ decay, we observed an unknown resonance X(1835) and study the controversial particle σ and κ. In $\psi(2S)$ decay, we test the "12% rule" via many decay modes and find many new χ_{cJ} decay channels. In ψ'' decay, we observed the non-D$\bar{D}$ decay via $\psi'' \to \pi^+\pi^- J/\psi$ and study the semi-leptonic decay of D meson. In addition, we give the preliminary ψ'' resonance parameters with higher precision.

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1. Introduction

The study of $c\bar{c}$ quarkonium has made a significant progress since it has been found in 1974. However, many problems and puzzles still remain unknown. The Beijing Spectrometer (BES) is a conventional solenoidal magnet detector that is described in detail in Ref. [1]. BESII is the upgraded version of the BES detector [2]. It is an important detector operated in charm energy region in the world. A lot of physics results have been published or reported at BES. We will present some recent BES results in this paper

2. J/ψ results

2.1 Observation of X(1835)

Two years ago, we observed an enhancement near $p\bar{p}$ threshold in $J/\psi \to \gamma p\bar{p}$. BW fit gives $M = 1859^{+3}_{-10}{}^{+5}_{-25} MeV/c^2$, $\Gamma < 30 MeV/c^2$. According to BES measurement, we infer there is a large branching ratio of $X(1860) \to p\bar{p}$. Furthermore, the large branching ratio indicates the X(1860) has strong coupling to $p\bar{p}$. There are some theoretical predictions for the property of X(1860). Recently, we observed a new resonance, X(1835), via $J/\psi \to \gamma\pi^+\pi^-\eta'$ [3]. It is likely to be a $p\bar{p}$ bound state since it dominantly decays to $p\bar{p}$ while its mass is above $p\bar{p}$ mass threshold.

2.2 The σ and κ

There have been hot debates on the existence of σ and κ. The decay of $J/\psi \to \omega\pi^+\pi^-$, with the ω decaying to $\pi^+\pi^-\pi^0$, is studied for σ production [4]. Different parameterizations of BW are used in PWA(Partial Wave Analysis). The averaged pole position is

$$(541 \pm 39) - i(252 \pm 42) MeV/c^2$$

BES observed the κ evidence in $J/\psi \to K^* K\pi$ decay channel [5], PWA gives its pole position

$$841 \pm 30^{+81}_{-73} - i(309 \pm 45^{+48}_{-72})$$

3. $\psi(2S)$ results

3.1 Test of "12% rule"

From perturbative QCD, it is expected that both J/ψ 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, it is the so-called "12%" rule,

$$Q_h = \frac{\mathscr{B}_{\psi(2S)\to h}}{\mathscr{B}_{J/\psi\to h}} = \frac{\mathscr{B}_{\psi(2S)\to e^+e^-}}{\mathscr{B}_{J/\psi\to e^+e^-}} \approx 12\% \tag{3.1}$$

In order to test this rule, Many $\psi(2S)$ decay channels have been investigated and their branching ratios are compared with the corresponding J/ψ decay channels [6, 7, 8]. Table 1 lists some BES measured results for $\psi(2S)$. One can find some channels follows this rule, some are enhanced and some are suppressed.

Table 1: Branching ratios for the $\psi(2S)$ and J/ψ(PDG) decays.

Mode	Channel	$\mathscr{B}(\psi(2S))$ $(\times 10^{-5})$	$\mathscr{B}(J/\psi)$ $(\times 10^{-4})$	Q_h (%)
	$\rho\pi$	$5.1 \pm 0.7 \pm 1.1$	127 ± 9	0.40 ± 0.11
	$K^{\star +}\underline{K}^{-} + c.c.$	$2.9^{+1.3}_{-1.7} \pm 0.4$	50 ± 4	$0.59^{+0.27}_{-0.36}$
	$K^{\star 0}\overline{K}^{0} + c.c.$	$13.3^{+2.4}_{-2.8} \pm 1.7$	42 ± 4	3.2 ± 0.8
	$\phi\pi^0$	< 0.41	< 0.068	–
	$\phi\eta$	$3.3 \pm 1.1 \pm 0.5$	6.5 ± 0.7	5.1 ± 1.9
VP	$\phi\eta'$	$2.8 \pm 1.5 \pm 0.6$	3.3 ± 0.4	8.5 ± 5.0
	$\omega\eta$	< 3.2	15.8 ± 1.6	< 2.0
	$\omega\eta'$	$3.1^{+2.4}_{-2.0} \pm 0.7$	1.67 ± 0.25	19^{+15}_{-13}
	$\omega\pi^0$	$1.87^{+0.68}_{-0.62} \pm 0.28$	4.2 ± 0.6	$4.4^{+1.8}_{-1.6}$
	$\rho\eta$	$1.78^{+0.67}_{-0.62} \pm 0.17$	1.93 ± 0.23	$9.2^{+3.6}_{-3.3}$
	$\rho\eta'$	$1.87^{+1.64}_{-1.11} \pm 0.33$	1.05 ± 0.18	$17.8^{+15.9}_{-11.1}$

3.2 Study of χ_{cJ}

Based the χ_{cJ} events from $\psi(2S)$ sample via radiative decay of $\psi(2S) \to \gamma\chi_{cJ}$, many hadronic decays of χ_{cJ} have been investigated. Table 2 lists some results. In addition, we measured the multipole amplitudes in radiative decay of $\psi(2S) \to \gamma\chi_{cJ}$ via $\psi(2S) \to \gamma\chi_{c0,2}, \chi_{c0,2} \to \pi^+\pi^-, K^+K^-$ [9]. The results are

$$a_2' = -0.051^{+0.054}_{-0.036}, \quad a_3' = -0.027^{+0.043}_{-0.029}$$

. The PWA of $\chi_{c0} \to \pi^+\pi^-K^+K^-$ was also performed [10]. The detailed analyses on $\chi_{cJ} \to$

Table 2: BES results for χ_{cJ} decay branching ratios($\times 10^{-3}$)

Decay channel	χ_{c0}	χ_{c1}	χ_{c2}
$K^*(892)K^*(892)$	$1.78 \pm 0.34 \pm 0.34$	$1.67 \pm 0.31 \pm 0.31$	$4.85 \pm 0.56 \pm 0.88$
$\omega\omega$	$2.29 \pm 0.58 \pm 0.41$	–	$1.77 \pm 0.47 \pm 0.36$
$K_S^0K_S^0$	$3.51 \pm 0.22 \pm 0.47$	< 0.08 (90% C.L.)	$0.89 \pm 0.12 \pm 0.13$
$K_S^0K_S^0\pi^+\pi^-$	$6.5 \pm 0.6 \pm 1.0$	$0.80 \pm 0.31 \pm 0.14$	$3.24 \pm 0.61 \pm 0.55$
$K_S^0K_S^0K^+K^-$	$1.83 \pm 0.47 \pm 0.33$	$0.31 \pm 0.19 \pm 0.06$	$0.33 \pm 0.24 \pm 0.06$

$K^{*0}(892)\bar{K}^{*0}(892), \omega\omega, K_sK_shh$ are presented in Refs. [11, 12, 13]

4. ψ'' results

4.1 Non-$D\bar{D}$ decay in ψ''

BES first reported ψ'' non-$D\bar{D}$ decay in $\psi'' \to \pi^+\pi^-J/\psi$, here J/ψ is tagged by $\mu^+\mu^-$ or e^+e^- pair. BES gives the measurement result, $\mathscr{B}(\psi'' \to \pi^+\pi^-J/\psi) = (0.34 \pm 0.14 \pm 0.09)\%$ [14]. This result has been confirmed by CLEO via both $\psi'' \to \pi^+\pi^-J/\psi$ and $\psi'' \to \pi^0\pi^0J/\psi$.

4.2 D meson exclusive semi-leptontic decay

The branching ratio of $D^0 \to K^-e^+\nu, \pi^+e^0\nu$ and $D^+ \to K^0e^+\nu$ can be used to calculation CKM elements $|V_{cs}|$ and $|V_{cd}|$ and measure the form factor $|f_+^K(0)|$ and $|f_+^\pi(0)|$. In addition, the ratio $\frac{\Gamma(D^0 \to K^- e^+ \nu)}{\Gamma(D^+ \to \bar{K}^0 e^+ \nu)}$ can be used to test isospin conservation. Table 3 lists some experimental results. With BES measured branching ratios, we obtain following results [15].

Table 3: Branching ratio for inclusive semi-leptonic decay(%)

Experiment	$D^0 \to K^- e^+ \nu_e$	$D^0 \to \pi^- e^+ \nu_e$	$D^+ \to \bar{K}^0 e^+ \nu_e$
BES	$3.82 \pm 0.40 \pm 0.27$	$0.33 \pm 0.13 \pm 0.03$	$8.59 \pm 1.59 \pm 0.67$
MARK-III	$3.4 \pm 0.5 \pm 0.4$	$0.39^{+0.23}_{-0.11} \pm 0.04$	$6.0^{+2.2}_{-1.3} \pm 0.7$
PDG	3.58 ± 0.18	0.36 ± 0.06	6.7 ± 0.9

$$|f_+^K(0)| = 0.78 \pm 0.04 \pm 0.03, \quad |f_+^\pi(0)| = 0.73 \pm 0.14 \pm 0.06, \quad \left|\frac{V_{cs}}{V_{cd}}\right|^2 = 0.043 \pm 0.01 \pm 0.003$$

4.3 Measurements of ψ'' and $\psi(2S)$ resonant parameters

Using hadronic cross-sections at 48 energy points from 3.65 GeV/c^2 to 3.85 GeV/c^2, we measure their resonance parameters of $\psi(2S)$ and ψ'' by fitting $\psi(2S)$ and ψ'' simultaneously. In such a way, the influence of $\psi(2S)$ radiative tail to ψ'' has been accounted precisely. The preliminary results for ψ'' are

$$M = 3772.8 \pm 1.3 MeV/c^2, \;\; \Gamma_{tot} = 25.5 \pm 3.1 MeV/c^2, \;\; \Gamma_{e^+e^-} = 224 \pm 30 eV/c^2$$

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