Recent results of Charmonium decays and transitions at BESIII

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Based on 106×10^6 ψ' events collected at BESIII detector in 2009, we study charmonium decays and transition decays. We measured the branching fractions of $\psi' \to \gamma\pi^0, \gamma\eta, \gamma\eta', \chi_{cJ} \to \gamma\rho, \gamma\omega, \gamma\phi, p\bar{p}K^+K^-$, and $VV(V = \omega, \phi)$. We also search for the decay mode of $\eta_c' \to VV(V = K^{*0}, \rho)$, but no obvious signal is found. We also studied charmonium properties via hadronic and radiative transitions. For example, h_c properties study, η_c mass and width measurement, first observation of η_c' in charmonium decay as well as the multipoles analysis of $\psi' \to \gamma\chi_{c2}$.

1 Introduction

The ratio of $R_{c\bar{c}}$ is defined as $R_{c\bar{c}} \equiv (\mathcal{B}(c\bar{c} \to \gamma\eta)/\mathcal{B}(c\bar{c} \to \gamma\eta')$. CLEO-c's experiments indicates that $R_{\psi'} \ll R_{J/\psi}$ with $R_{\psi'} < 1.8\%$ at the 90% C.L. and $R_{J/\psi} = (21.1 \pm 0.9)\%$ [1]. Such a small $R_{\psi'}$ is unanticipated, and it poses a significant challenge to our understanding of the $c\bar{c}$ bound states. The two-photon transition of $\psi' \to \gamma\gamma J/\psi$ is more sensitive to the coupled-channel effect and thus provides a unique opportunity to investigate the issues [2]. Meanwhile, the two-photon spectroscopy has been a very powerful tool for the study of the excitation spectra of a variety of systems with a side range of sizes, such as molecules atomic hydrogen and positronium. Doubly radiative decays of the type $\psi' \to \gamma X \to \gamma\gamma V$, where V is either a ϕ, ρ^0, or ω meson, provide information on the flavor content of the C-even resonance X and on the gluon hadronization dynamics in the process. The spin and charge dependent couplings in radiative decays reveal detailed information which is particularly useful in the search for glueball and hybrid states. CLEO's measurement failed to find any obvious ϕ signal due to the small statistic. Decays of the χ_{c1} into $\phi\phi$,$\omega\omega$ and $\omega\phi$ violate the helicity selection rule (HSR). In addition, the decays of $\chi_{cJ} \to \omega\phi$ are doubly OZI suppressed and have yet to be observed. Recently, long-distance effects in χ_{c1} decay have been proposed to account for the HSR violation. Precise measurement of $\chi_{c1} \to VV$ decays will help clarify the influence of long-distance effects in this energy region. $\eta_c(2S) \to VV$ are supposed to be highly suppressed according to some theoretical prediction, but have a higher production in other theory. The measurement of $\eta_c(2S) \to VV$ may help in understanding the role played by charmed meson loops in $\eta_c(2S) \to VV$. h_c is firstly observed by CLEO collaboration with E1 tagged mode. However, they haven't measured its width, nor observed h_c without E1-tagged. The resonant parameter of η_c have been measured by many experiments, but the differences between them are awfully large for both mass and width. $\eta_c(2S)$ has been found in many decay modes, but haven't been observed in charmonium decay. In general, the transition amplitude of radiative decays of charmonium states is dominated by the electric dipole (E1) contribution, with higher multipoles suppressed by powers of photon energy divided by charm quark mass. The search for contributions of higher-order multipole

amplitudes is of interest as a source of information on the charm quarks magnetic moment.

1.1 Charmonium decays

For the branching fraction measurements of $\psi' \to \gamma\pi^0, \gamma\eta, \gamma\eta', \chi_{cJ} \to \gamma\rho, \gamma\omega, \gamma\phi, p\bar{p}K^+K^-$, and $VV(V = \omega, \phi)$. The events selection criteria can be found in the published paper [5,6,8]. For the search for $\eta_c' \to VV$, one can refer to [9] for detail. The general selection criteria for charged track and neutral shower are below. We require that each charged track (except those from K_S decays) is consistent with originating from within 1 cm in the radial direction and 10 cm along the beam direction of the run-by-run-determined interaction point. The tracks must be within the MDC fiducial volume, $|\cos\theta| < 0.93$. Photons are reconstructed from the isolated showers in the EMC. The energy deposited in the nearby TOF counter is included to improve the reconstruction efficiency and energy resolution. Photon energies are required to be greater than 25 MeV in the EMC barrel region($|\cos\theta| < 0.8$); in the EMC end caps ($0.86 < |\cos\theta| < 0.92$) this requirement is increases to 50 MeV. The showers in the angular range between the barrel and end cap are poorly reconstructed and excluded from the analysis. Moreover, the EMC timing of the photon candidate must be in coincidence with collision events, $0 \le t \le 700$ ns , to suppress electronic noise and energy deposits unrelated to the events. π^0, η is reconstructed by $\gamma\gamma$ invariant mass and ρ, ω, and ϕ are reconstructed by $\pi^+\pi^-$, $\pi^+\pi^-\pi^0$, and K^+K^- invariant mass. Table 1 shows the measurement results for $\psi' \to \gamma P(P = \pi^0, \eta, \eta')$.

Table 1: Branching fractions($\times 10^6$) of $\psi' \to \gamma P$, where the first errors are statistical and the second ones are systematic, and the comparison with the PDG values.

Mode	BESIII	PDG
hline $\psi' \to \gamma\pi^0$	$1.58 \pm 0.40 \pm 0.13$	≤ 5
$\psi' \to \gamma\eta$	$1.38 \pm 0.48 \pm 0.09$	≤ 2
$\psi' \to \gamma\eta'$	$126 \pm 3 \pm 8$	121 ± 8

Figure 1 (a) and (b) show the fit to the recoiling mass of lower-energy photon for $\gamma\gamma e^+e^-$ and $\gamma\gamma\mu^+\mu^-$ final states. Clear χ_{cJ} signal can be seen. Figure 1 (e) and (f) shows the $\gamma\gamma$ recoiling mass with the events in the region of 3.44 GeV/c^2 < R_{sm} <3.48 GeV/c^2. Here, R_{sm} denotes the recoiling mass of lower-energy photon. Most events from the known decay modes, $\psi' \to \gamma\chi_{cJ}, \chi_{cJ} \to \gamma J/\psi$ and $\psi' \to \pi^0(\eta)J/\psi$ doesn't fall into this region. An excess of data above known background can be seen around J/ψ nominal mass in figure 1(e) and (f), which is expected from the sought after two-photon process. With the number of events from fit, we obtain the branching fraction of two-photon process $\psi' \to \gamma\gamma J/\psi$ is $(3.3 \pm 0.6^{+0.8}_{-1.1}) \times 10^{-4}$ with the statistical significance of 3.8σ. Table 2 shows the results of $\chi_{cJ} \to \gamma V$. We also list the CLEO's measurements and some theoretical predictions. The polarization of $\chi_{c1} \to \gamma V$ have been studied according to their angular distribution information, and it is found that longitudinal polarization is dominant which is consistent with theoretical prediction [7]. Table 3 shows the measured branching fractions of $\chi_{cJ} \to p\bar{p}K^+K^-$. For $\chi_{cJ} \to VV$, we confirm the previous $\chi_{c0,2} \to \phi\phi, \omega\omega$ with higher precision. Besides, we observed the decay of $\chi_{c1} \to \phi\phi, \omega\omega$ and $\chi_{cJ} \to \omega\phi$ for the first time. Table 4 shows the measurement results. In the search for $\eta_c' \to VV$, we haven't observed any obvious signal in $\rho^0\rho^0$, $K^{*0}\bar{K}^{*0}$, and $\phi\phi$. As a results we just give the upper limits on the decay fractions, which are $\mathcal{B}(\eta_c' \to \rho^0\rho^0) < 3.1 \times 10^{-3}$, $\mathcal{B}(\eta_c' \to K^{*0}\bar{K}^{*0}) < 5.4 \times 10^{-3}$, and $\mathcal{B}(\eta_c' \to \phi\phi) < 2.0 \times 10^{-3}$.

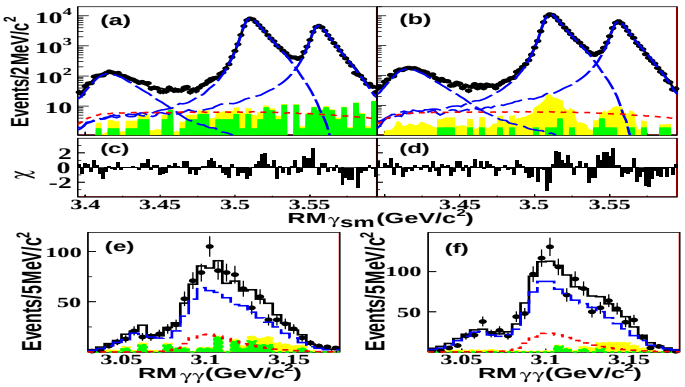

Figure 1: The distribution of the recoiling mass of lower-energy photon and $\gamma\gamma$ in $\gamma\gamma e^+e^-$ and $\gamma\gamma\mu^+\mu^-$ final states.

Table 2: Branching fractions on $\chi_{cJ} \to \gamma V$. The upper limit is set at 90% C.L.

Mode	CLEO	pQCD	QCD	QCD+QED	this experiments
hline $\chi_{c0} \to \gamma\phi$	< 9.6	1.2	3.2	2.0	< 10.5
$\chi_{c1} \to \gamma\phi$	$243 \pm 19 \pm 22$	14	41	42	$228 \pm 13 \pm 22$
$\chi_{c2} \to \gamma\phi$	< 50	4.4	13	38	< 20.8
$\chi_{c0} \to \gamma\omega$	< 8.8	0.13	0.35	0.22	< 12.9
$\chi_{c1} \to \gamma\omega$	$83 \pm 15 \pm 12$	1.6	4.6	4.7	$69.7 \pm 7.2 \pm 6.6$
$\chi_{c2} \to \gamma\omega$	< 7.0	0.5	1.5	4.2	< 6.1
$\chi_{c0} \to \gamma\phi$	< 6.4	0.46	1.3	0.03	< 16.2
$\chi_{c1} \to \gamma\phi$	< 26	14	3.6	11	$25.8 \pm 5.2 \pm 2.3$
$\chi_{c2} \to \gamma\phi$	< 13	1.1	3.3	6.5	< 8.1

2 Charmonium transitions

The event selection criteria for $\psi' \to \pi^0 h_c, \gamma\eta_c, \eta_c \to X$(X denotes a certain final state), $\psi' \to \gamma\eta_c', \eta_c' \to K_S K\pi$, and $\psi' \to \gamma\pi^+\pi^-, K^+K^-$ can be found in [10,11,12,13]. The h_c mass is confirmed with E1-tagged mode. It is found to be $3525.40 \pm 0.13 \pm 0.18$ MeV/c^2. In addition, we measure its width for the first time. It is found to be $0.73 \pm 0.45 \pm 0.28$ MeV, or < 1.44 MeV at 90% C.L. h_c signal can also be observed without E1-tagged mode. Therefore, we gave the absolute branching fraction $\mathcal{B}(\psi' \to \pi^0 h_c) = (8.4 \pm 1.3 \pm 1.0) \times 10^{-4}$ and $\mathcal{B}(h_c \to \gamma\eta_c) = (54.3 \pm 6.7 \pm 5.2)\%$. Meanwhile, h_c is also observed in 16 η_c exclusive decay channels. Figure 2 shows the π^0 recoil mass of sum 16 η_c exclusive decay channels. A global fit yields the preliminary mass and width, $3525.40 \pm 0.13 \pm 0.18$ MeV/c^2 and $0.73 \pm 0.45 \pm 0.28$ MeV. One finds that these results are very consistent with those in inclusive measurement. For η_c mass and width measurement, we investigate the transition decay of $\psi' \to \gamma\eta_c$, η_c decaying to $K_S K^+\pi^-, K^+K^-\pi^0, \eta\pi^+\pi^-, KsK^+\pi^+\pi^-\pi^0$, and $3(\pi^+\pi^-)$ final states. In the fit of mass spectrum, we have considered the interference between resonant and non-resonant state, the mass-dependent efficiency, the factors of the radiative photon energy reflect the expected energy dependence of the M1 matrix element. A global fit gives $M = 2984.3 \pm 0.6 \pm 0.6$ MeV/c^2, $\Gamma = 32.0 \pm 1.2 \pm 1.0$ MeV. η_c' has been observed in B decay, two-photon process and double charmonium production, but hasn't been reported in charmonium decay. The experimental challenge is how to search for the soft radiative photon which has a energy of about 50 MeV. We search η_c' signal in $\psi' \to K^+K^-\pi$ channel, including $K_S^0 K^\pm\pi^\mp$ and $K^+K^-\pi^0$. Figure 3 shows the invariant mass $K_S^0 K^\pm\pi^\mp$. The small bump is the η_c' signal. The fit yields $N_{\eta_c'} = 81 \pm 14$ for $K_S^0 K^\pm\pi^\mp$ channel and 46 ± 11 for $K^+K^-\pi^0$ channel. The $K_S^0 K^\pm\pi^\mp$ channel determines primarily the precision for the η_c' mass and width measurements in the simultaneous fit with

Table 3: Branching fractions($\times 10^{-4}$) on $\chi_{cJ} \to p\bar{p}K^+K^-$ final state. The upper limit is set at 90% C.L.

modes	χ_{c0}	χ_{c1}	χ_{c2}
$p\bar{p}K^+K^-$	$1.24 \pm 0.20 \pm 0.18$	$1.35 \pm 0.15 \pm 0.19$	$2.08 \pm 0.19 \pm 0.30$
$\bar{p}K^+\Lambda(1520) + c.c.$	$3.00 \pm 0.58 \pm 0.50$	$1.81 \pm 0.38 \pm 0.28$	$3.06 \pm 0.50 \pm 0.54$
$\Lambda(1520)\bar{\Lambda}(1520)$	$3.18 \pm 1.11 \pm 0.53$	< 1.00	$5.05 \pm 1.29 \pm 0.93$
$p\bar{p}\phi$	$0.61 \pm 0.12 \pm 0.09$	< 0.18	$030 \pm 0.09 \pm 0.04$

Table 4: Branching fractions($\times 10^{-4}$) on $\chi_{cJ} \to \phi\phi, \omega\omega, \omega\phi$.

modes	χ_{c0}	χ_{c1}	χ_{c2}	final state
$\phi\phi$	$8.0 \pm 0.3 \pm 0.8$	$4.4 \pm 0.3 \pm 0.5$	$10.7 \pm 0.3 \pm 1.2$	$2(K^+K^-)$
$\omega\omega$	$9.5 \pm 0.3 \pm 1.1$	$6.0 \pm 0.3 \pm 0.7$	$8.9 \pm 0.3 \pm 1.1$	$2(\pi^+\pi^-\pi^0)$
$\omega\phi$	$1.2 \pm 0.1 \pm 0.2$	$0.22 \pm 0.06 \pm 0.02$	< 0.2	$K^+K^-\pi^+\pi^-\pi^0$

the results $M_{\eta_c'} = 3637.6 \pm 2.9 \pm 1.6$ MeV/c^2 and $\Gamma_{etacp} = 16.9 \pm 6.4 \pm 4.8$ MeV, respectively. The combined statistical significance is larger than 10.2σ. The preliminary branching ratio is $\mathcal{B}(\psi' \to \gamma\eta_c') = (6.8 \pm 1.1 \pm 4.5) \times 10^{-4}$. By the simultaneous fit to the angular distribution of pion and kaon in $\psi' \to \gamma\chi_{c2}$,$\chi_{c2} \to \pi^+\pi^-, K^+K^-$, we obtain the normalized high-order parameter M2 and E3. They are $M2 = 0.046 \pm 0.010 \pm 0.013$ and $E3 = 0.015 \pm 0.008 \pm 0.018$. where the first errors are statistical and the second systematic.

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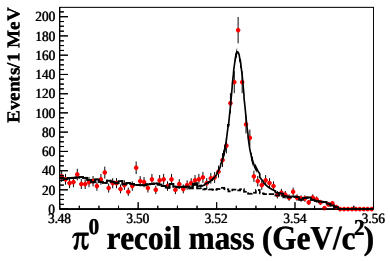

Figure 2: Sum of π^0 recoiling mass to 16 η_c exclusive decay channels

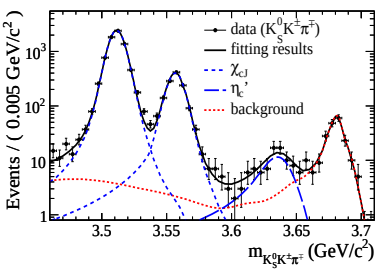

Figure 3: The fit to $K_S K\pi$ invariant mass.