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Recent BESIII results in charmonium physics

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Based on the world largest ψ' data sample collected with the BESIII experiment at the BEPCII collider, we performed measurements on h_c, η_c, and η_c'. The results include the masses, widths, and production rates of these resonances.

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1. Introduction

BEPCII/BESIII [1] is an upgrade facility from the previous BEPC/BESII experiment. The BESIII spectrometer consists of a main drift chamber with momentum resolution 0.5% at 1 GeV/c, an electromagnetic calorimeter with energy resolution 2.5% at 1.0 GeV, a Time-Of-Flight counter, a superconducting magnet with a magnetic strength of 1 T, and a muon chamber system made of resistive plate chambers.

Based on 106×10^6 [2] ψ' events taken in 2009, charmonium spectroscopy is widely studied.

2. Measurements of h_c with $\psi'\to\pi^0h_c$

As the P-wave spin singlet, h_c is first observed by E835 experiment [3] with scanning antiproton energy. Later, CLEO Collaboration observed the h_c in the cascade process $\psi'\to\pi^0h_c$, $h_c\to\gamma\eta_c$ with both inclusive and exclusive measurements [4, 5]. There are theoretical predictions [6] for the production and decays of h_c, which can be tested with the largest ψ' data sample at BESIII. Both E1-tagged and E1-untagged method in $h_c\to\gamma\eta_c$ are performed at BESIII to measure the branching fraction of $\psi'\to\pi^0h_c$ [7]. The results are shown in Fig. 1. The mass and width of h_c determined

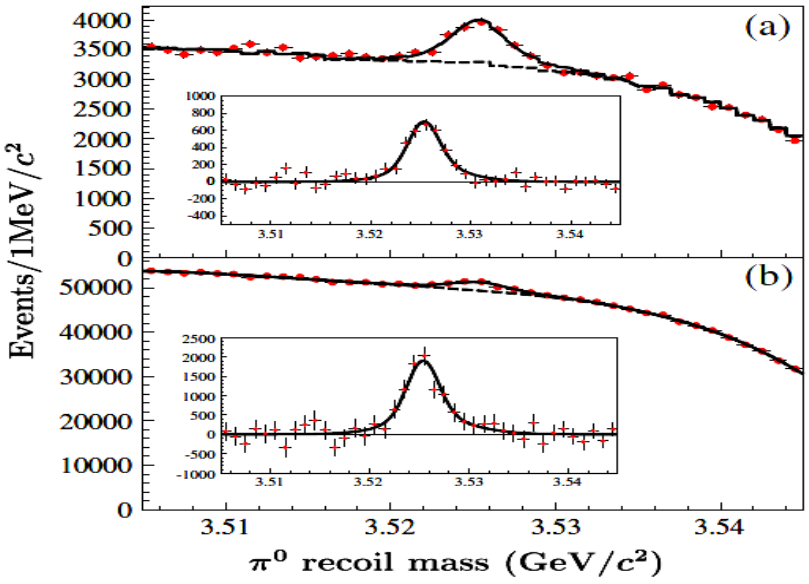

Figure 1: The recoiling mass of the tagged π^0 in $\psi'\to\pi^0h_c$: (a) for the E1 tagged method, (b) for the E1 untagged method.

with the E1 tagged method are $M_{h_c}=3525.40\pm0.13\pm0.18$ MeV/c^2 and $\Gamma_{h_c}=0.73\pm0.45\pm0.28$ MeV. The mass split $\Delta M_{hf}\equiv\langle M(1^3P)\rangle-M(1^1P_1)=-0.10\pm0.13\pm0.18$ MeV/c^2, which is consistent with zero predicted by the potential model. The branching fractions are determined to be $\mathscr{B}(\psi'\to\pi^0h_c)=(8.3\pm1.3\pm1.0)\times10^{-4}$ and $\mathscr{B}(h_c\to\gamma\eta_c)=(54.3\pm6.7\pm5.2)\%$, which also agree with the theoretical predictions. Exclusive measurements are also studied with sixteen η_c decay channels, and the simultaneous fit is shown in Fig. 2. Results from the exclusive measurement are: $M_{h_c}=3525.31\pm0.11\pm0.14$ MeV/c^2, and $\Gamma_{h_c}=0.70\pm0.28\pm0.22$ MeV. They are consistent with the previous measurement at CLEO [5].

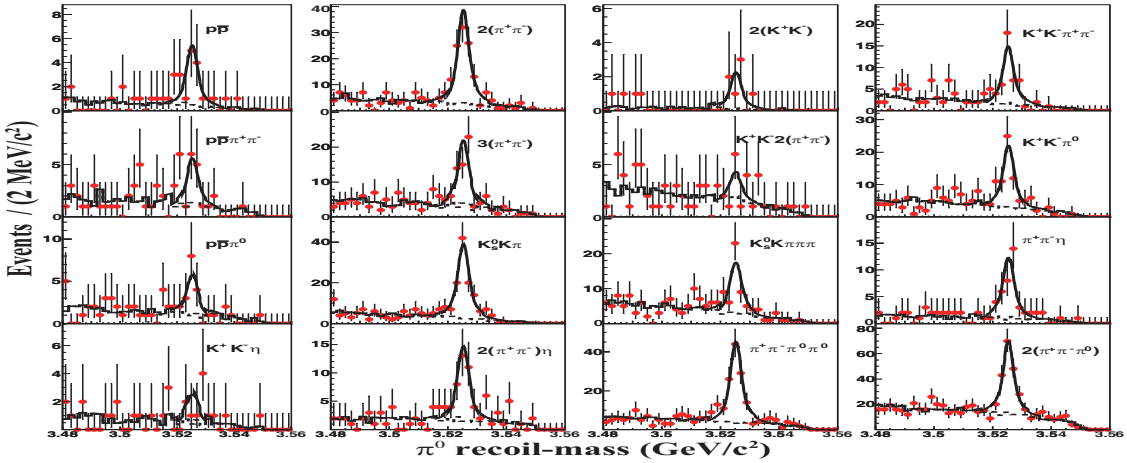

Figure 2: Simultaneous fit to 16 exclusive decay modes.

3. Measurements of the mass and width of the η_c using $\psi' \to \gamma\eta_c$

Properties of η_c are not well understood although it has been observed for many years. There are obvious discrepancies between results from different experiments [8]. An obvious distortion in the line shape of η_c is reported by CLEO [9], but similar effect is not observed in $\psi' \to \pi^0 h_c$, $h_c \to \gamma\eta_c$ at BESIII.

Measurement of η_c at BESIII is performed with six decay channels, including $K^0_S K\pi$, $K^+K^-\pi^0$, $\pi^+\pi^-\eta$, $K^0_S K3\pi$, $K^+K^-\pi^+\pi^-\pi^0$ and $3(\pi^+\pi^-)$ [10]. A simultaneous fit with unique η_c mass and width is performed on the η_c mass spectra, where a full interference between η_c and non-resonant ψ' radiative decays is considered and the quantum number of the non-η_c components are assumed to be 0^{-+}. The corresponding relative phases in different decay modes are found to be consistent within 3σ, which are constrained to the same value in the final fit. The simultaneous fit is shown in Fig. 3. The obtained results are $M_{\eta_c} = 2984.3 \pm 0.6 \pm 0.6$ MeV/c^2, $\Gamma_{\eta_c} = 32.0 \pm 1.2 \pm 1.0$ MeV, $\phi_1 = 2.40 \pm 0.07 \pm 0.08$ rad (constructive), and $\phi_2 = 4.19 \pm 0.03 \pm 0.09$ rad (destructive). The BESIII results are consistent with that from two-photon production [11, 12, 13]. The precision of the measured mass and width are improved.

4. First observation of the M1 transition $\psi' \to \gamma\eta_c'$

η_c' is first observed by Belle Collaboration [14] in $B \to KK_S K^-\pi^+$, which is also expected in the radiative transition of ψ'. According to the potential model, the branching fraction is predicted to be $\mathscr{B}(\psi' \to \gamma\eta_c') = (0.1 - 6.2) \times 10^{-4}$ [15].

BESIII performed a searching for the η_c' in several decay modes, and signal is only observed in the $K\bar{K}\pi$ [16] final state. Figure 4 shows the fit result to the mass spectrum of $K\bar{K}\pi$. With a simultaneous fit we obtain the mass and width of η_c': $M_{\eta_c'} = 3637.6 \pm 2.9 \pm 1.6$ MeV/c^2, and $\Gamma_{\eta_c'} = 16.9 \pm 6.4 \pm 4.8$ MeV. The product branching fraction is determined to be $\mathscr{B}(\psi' \to \gamma\eta_c') \times \mathscr{B}(\eta_c' \to K\bar{K}\pi) = (1.30 \pm 0.20 \pm 0.30) \times 10^{-5}$. Using the previous measurement $\mathscr{B}(\eta_c' \to K\bar{K}\pi) =$

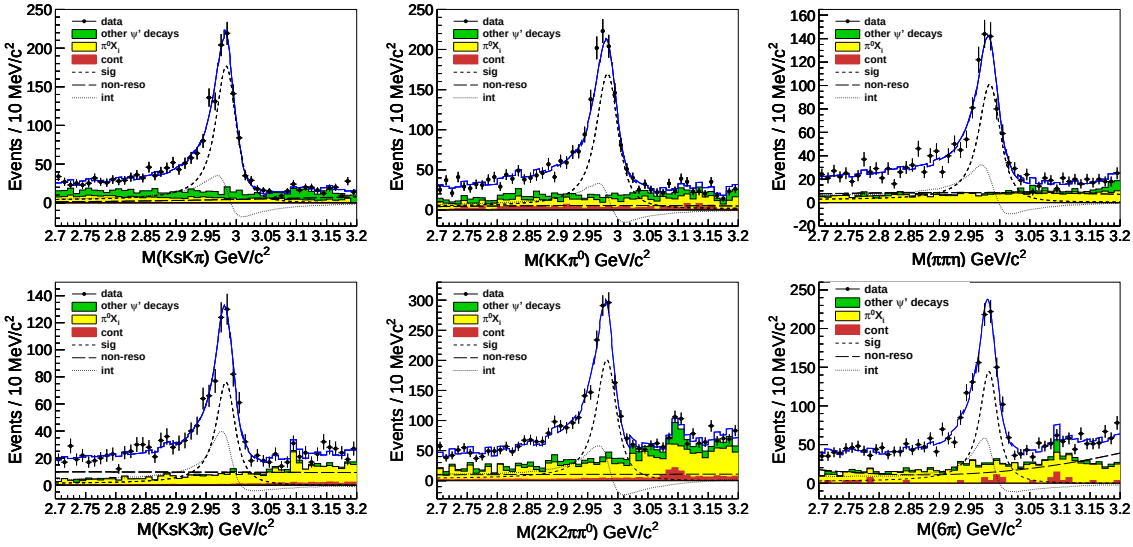

Figure 3: The simultaneous fit of six decay channels.

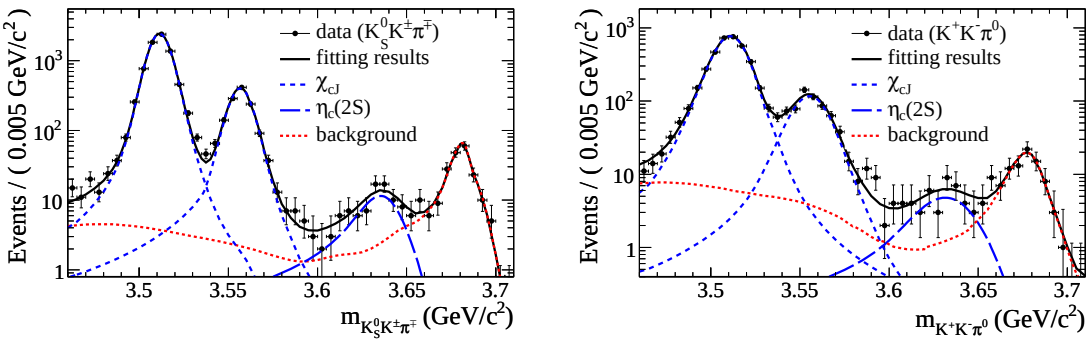

Figure 4: The simultaneous fit to the $K\bar{K}\pi$ mass spectrum.

$(1.9 \pm 0.4 \pm 1.1)\%$ from BaBar [17], the M1 transition rate is determined to be $\mathscr{B}(\psi' \to \gamma\eta_c') = (6.8 \pm 1.1 \pm 4.5) \times 10^{-4}$.

Searching for η_c' is also performed with the VV final states, including $\rho^0\rho^0$, $K^{*0}\bar{K}^{*0}$, and $\phi\phi$. The intermediate charmed meson loops can be taken as a mechanism to evade the helicity selection rule, which provides possible explanation for the long standing "$\rho\pi$" puzzle. Considering this effect, the production of $\eta_c' \to VV$ is expected to be quite high. Based on 106 M ψ' data, no significant η_c' signal is found in the three final states we studied, and the branching fraction upper limits are determined to be $\mathscr{B}(\eta_c' \to \rho^0\rho^0) < 3.1 \times 10^{-3}$, $\mathscr{B}(\eta_c' \to K^{*0}\bar{K}^{*0}) < 5.4 \times 10^{-3}$, and $\mathscr{B}(\eta_c' \to \phi\phi) < 2.0 \times 10^{-3}$ [18], which are lower than the theoretical predictions [19].

5. Summary

With the 106×10^6 ψ' data collected by BESIII, the following results about Charmonium spectroscopy are obtained: the properties of h_c are measured with both inclusive and exclusive methods; the properties of η_c are precisely measured using the radiative decays of ψ', where the interference between η_c decays and non-resonant decays is taken into account; the M1 transition $\psi' \to \gamma\eta_c'$ is first observed with the $K\bar{K}\pi$ final state.

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