LATEST RESULTS FROM BESIII*

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Recent results of the BESIII experiment are presented, including the first observation of the M1 transition $\psi(3686) \rightarrow \gamma\eta_c(2S)$, the measurement of $J/\psi \rightarrow 3\gamma$, η_c decays into baryon anti-baryon pairs, the discovery of $Z_c(3900)$, and the study of $J/\psi \rightarrow \omega p\bar{p}$.

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1. Introduction

The BESIII/BEPCII is an upgrade to the previous BEPC/BES, which is located in the Institute of High Energy Physics (Beijing, China). The main physics goals of the experiment are precision measurements in the τ -charm domain.

BEPCII is a modern accelerator featuring multi-bunch, double ring and high luminosity, operating at beam energies varying between 1.0 and 2.3 GeV. The design luminosity is $1 \times 10^{33} \text{cm}^{-2} \text{s}^{-1}$. The BESIII detector is a new high performance general purpose detector. It is composed of a helium-gas based drift chamber (MDC), a time-of-flight (TOF) system, a CsI (Tl) electro-magnetic calorimeter (EMC), a super-conducting solenoid magnet and a resistive plate chambers based muon chamber. The momentum resolution at 1 GeV/c is 0.5%. The energy resolution of 1 GeV photons is 2.5%.¹

The BESIII experiment has already collected large data samples on J/ψ (1.2 billion events), $\psi(3686)$ (0.6 billion events), $\psi(3770)$ (2.9 fb^{-1}), $\psi(4040)$ (0.5 fb^{-1}), $Y(4260)$ (1.9 fb^{-1}), $Y(4360)$ (0.5 fb^{-1}). With these data samples, many papers have been published. In this paper, a selection of topics will be presented.

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2. Highlights from BESIII

The BESIII collaboration has published a variety of papers with many new results in the field of light hadron physics, charmonium spectroscopy, charmonium decays and XYZ physics. A number of new hadronic states were discovered or confirmed, and various decay properties were measured for the first time. Here, we show recent highlights from the BESIII.

2.1. First observation of the M1 transition $\psi(3686) \rightarrow \gamma\eta_c(2S)$

$\eta_c(2S)$ was first observed in B decays by the Belle Collaboration,² and confirmed in two-photon production³⁻⁴ and in double-charmonium production process $e^+e^- \rightarrow J/\psi c\bar{c}$.⁵⁻⁶ It is also expected in radiative transitions of $\psi(3686)$. According to a potential model,⁷ the branching fraction is predicted to be $B(\psi(3686) \rightarrow \gamma\eta_c(2S)) = (0.1 - 6.2) \times 10^{-4}$.

At BESIII, $\eta_c(2S)$ is observed for the first time in the radiative transition of $\psi(3686)$, in the reaction $\psi(3686) \rightarrow \gamma\eta_c(2S)$, $\eta_c(2S) \rightarrow K\bar{K}\pi$.⁸ Fig. 1 shows the fit to the mass spectrum of $K_S^0 K^\pm \pi^\mp$ and $K^+ K^- \pi^0$. With a simultaneous fit, we obtained the mass $M_{\eta_c(2S)} = 3637.6 \pm 2.9 \pm 1.6 \text{ MeV}/c^2$, and the width $\Gamma_{\eta_c(2S)} = 16.9 \pm 6.4 \pm 4.8 \text{ MeV}/c^2$. The product branching fraction is determined to be $B(\psi(3686) \rightarrow \gamma\eta_c(2S)) \times B(\eta_c(2S) \rightarrow K\bar{K}\pi) = (1.30 \pm 0.20 \pm 0.30) \times 10^{-5}$. Using the previous measurement $B(\eta_c(2S) \rightarrow K\bar{K}\pi) = (1.9 \pm 0.4 \pm 1.1)\%$ from BaBar,⁹ the M1 transition rate is determined to be $B(\psi(3686) \rightarrow \gamma\eta_c(2S)) = (6.8 \pm 1.1 \pm 4.5) \times 10^{-4}$.

2.2. Evidence for $\eta_c \rightarrow \gamma\gamma$ and measurement of $J/\psi \rightarrow 3\gamma$

Decays of charmonia to multiple photons such as $J/\psi \rightarrow 3\gamma$ play an important role in the understanding of the strong interaction.¹⁰ This type of decay has a relatively simple theoretical description, and the experimental measurements allow for a fundamental test of non-perturbative QCD.¹¹ At BESIII, we performed the most precise measurement of the $J/\psi \rightarrow 3\gamma$ branching fraction using $\psi(3686) \rightarrow \pi^+\pi^- J/\psi$ decays.¹² In addition to the direct 3γ decay, the sequential decay $J/\psi \rightarrow \gamma\eta_c$, $\eta_c \rightarrow \gamma\gamma$ is also measured in this analysis.

Fig. 1. The invariant mass spectrum for $K_S^0 K^\pm \pi^\mp$ (left panel), $K^+ K^- \pi^0$ (right panel), and the simultaneous likelihood fit to the three resonances and combined background sources.

Fig. 2. Scatter plots of $M(\gamma\gamma)_{lg}$ versus $M(\gamma\gamma)_{sm}$ for (c) data and for MC simulations of the processes (a) $J/\psi \rightarrow \gamma\pi^0/\eta/\eta' \rightarrow 3\gamma$, (b) $J/\psi \rightarrow \gamma f_2(1270) \rightarrow \gamma(\gamma\gamma)\pi^0(\gamma\gamma)\pi^0$, (d) $J/\psi \rightarrow 3\gamma$, and (f) $J/\psi \rightarrow \gamma\eta_c \rightarrow 3\gamma$. Plot (e) shows the distribution of data after excluding backgrounds from $J/\psi \rightarrow \gamma\pi^0/\eta/\eta'$, where the empty bands are due to the requirements on any two-photon combination. The vertical lines indicate the mass windows to reject π^0 , η and η' .

Distributions of $M(\gamma\gamma)_{lg}$ versus $M(\gamma\gamma)_{sm}$ are shown in Fig. 2, where $M(\gamma\gamma)_{lg}$ and $M(\gamma\gamma)_{sm}$ are the largest and smallest two-photon invariant masses among the three combinations, respectively. Events from the background processes $J/\psi \rightarrow \gamma\pi^0/\eta/\eta' \rightarrow 3\gamma$ are clearly seen within the three vertical bands. After removing these background, the survived events include four contributions, $J/\psi \rightarrow 3\gamma$, $J/\psi \rightarrow \gamma\eta_c \rightarrow 3\gamma$, $J/\psi \rightarrow \gamma\pi^0\pi^0$, and small portion of backgrounds from $J/\psi \rightarrow \gamma\pi^0/\eta/\eta'$ and non- J/ψ decays. The right plot in Fig. 2 shows the MC simulation of $J/\psi \rightarrow \gamma\eta_c \rightarrow 3\gamma$. To extract the yields of $J/\psi \rightarrow 3\gamma$, $J/\psi \rightarrow \gamma\eta_c \rightarrow 3\gamma$, a two-dimensional maximum likelihood fit is performed on the $M(\gamma\gamma)_{lg}$ and the χ^2_{4C} distributions. The branching fraction for $J/\psi \rightarrow 3\gamma$ is measured to be $(11.3 \pm 1.8 \pm 2.0) \times 10^{-6}$. Evidence of direct decay of η_c to two photons is seen, with the product branching fraction $B(J/\psi \rightarrow \gamma\eta_c, \eta_c \rightarrow \gamma\gamma) = (4.5 \pm 1.2 \pm 0.6) \times 10^{-6}$.

2.3. η_c decays into baryon anti-baryon pairs

In the charmonium-mass region, there are many contradictions between pQCD calculations and experimental measurements. In particular, the pQCD helicity selection rule^{13–14} is violated in many exclusive charmonium-decay processes, such as $\eta_c \rightarrow B_8\bar{B}_8$, where $B_8\bar{B}_8$ denotes octet baryon anti-baryon pairs. Many attempts have been made to understand these contradictions. In Ref. 15, a charmed-meson loop model is proposed and the results agree with the measured branching fractions of $\eta_c \rightarrow p\bar{p}$ and $\eta_c \rightarrow \Lambda\bar{\Lambda}$. The measurement of further B_8 final state decays could provide more stringent test of this model. For this reason, we measured the branching fractions of $\eta_c \rightarrow \Sigma^+\bar{\Sigma}^-$ and $\eta_c \rightarrow \Xi^-\bar{\Xi}^+$ for the first time via the $J/\psi \rightarrow \gamma\eta_c$ radiative decay process.¹⁶

The selected events and the fitted curves for both decay processes are shown in Fig. 3. Very nice η_c peak can be seen in both processes. The branching fractions are obtained: $B(\eta_c \rightarrow \Sigma^+\bar{\Sigma}^-) = (2.11 \pm 0.28 \pm 0.18 \pm 0.50) \times 10^{-3}$, and $B(\eta_c \rightarrow \Xi^-\bar{\Xi}^+) = (0.89 \pm 0.16 \pm 0.08 \pm 0.21) \times 10^{-3}$, where the first uncertainties are statistical,

Fig. 3. Invariant mass distributions of data and MC background channels together with the fitted curves for (a) $\Sigma^+\Sigma^-$, and (b) $\Xi^-\Xi^+$.

the second systematic, and the third uncertainties are from the precision of the intermediate branching fractions. Comparing the results of our measurements with the predictions from charmed-meson loop calculations, we find that the measured branching fraction of $\eta_c \rightarrow \Sigma^+\Sigma^-$ agrees with the prediction, but the measured branching fraction of $\eta_c \rightarrow \Xi^-\Xi^+$ is larger than the prediction.¹⁵

2.4. Discovery of $Z_c(3900)$

$Y(4260)$ was discovered in the initial-state-radiation(ISR) process $e^+e^- \rightarrow \gamma_{ISR}\pi^+\pi^-J/\psi$,¹⁷ and further observations^{18–21} also relied on the ISR technique (using data from B factory). One disadvantage of the ISR technique is the huge reduction of yield arising from emitting a high energy ISR photon. Charm factories are more suitable to study the mysterious $Y(4260)$.

At BESIII, using 525 pb^{-1} (part of the total 1.9 fb^{-1}) data collected at a center-of-mass energy of $\sqrt{s} = (4.260 \pm 0.001) \text{ GeV}$, a study of the process $e^+e^- \rightarrow \pi^+\pi^-J/\psi$ was performed.²² The cross section is measured to be $(62.9 \pm 1.9 \pm 3.7) \text{ pb}$, which agrees with the existing results from the BaBar,²¹ Belle,¹⁹ and CLEO²⁰ experiments. In addition, a charged structure with a mass of $(3899.0 \pm 3.6 \pm 4.9) \text{ MeV}/c^2$ and width of $(46 \pm 10 \pm 20) \text{ MeV}/c^2$ is observed in the $\pi^\pm J/\psi$ invariant mass spectrum, as shown in Fig. 4. This has also been observed by Belle²³ and one analysis using the CLEO data.²⁴ This structure couples to charmonium and has an electric charge, which is suggestive of a state containing more quarks than just a charm and anti-charm quarks. It is also worth to mention that there are already many model-dependent calculations that attempt to explain this charmoniumlike structure. The nature of the $Z_c^\pm$ is still not completely understood. The BESIII Collaboration will increase the statistics to study its properties and decays.

2.5. Study of $J/\psi \rightarrow \omega p \bar{p}$

An anomalous enhancement near the threshold of the $p\bar{p}$ system, namely $X(p\bar{p})$, was first observed by the BESII experiment in the radiative decay $J/\psi \rightarrow \gamma p \bar{p}$,²⁵ and has been confirmed by the CLEO and BESIII experiments^{26–28}. A number of

Fig. 4. Dalitz distributions of $M^2(\pi^+\pi^-)$ vs. $M^2(\pi^+J/\psi)$ for selected $e^+e^- \rightarrow \pi^+\pi^-J/\psi$ events. The inset shows background events from the J/ψ mass sidebands (not normalized)

theoretical speculations have been proposed to interpret the nature of this structure. To understand the nature of this near-threshold $p\bar{p}$ structure, the investigation in other J/ψ decay modes will be helpful.

Fig. 5. (Left) Dalitz plot of $M^2(\omega\bar{p})$ versus $M^2(\omega p)$; (Right) Near-threshold $p\bar{p}$ invariant mass spectrum.

Using a data sample of 225 million J/ψ events, the analysis of $J/\psi \rightarrow \omega p\bar{p}$ via the decay channel $\omega \rightarrow \gamma\pi^0$ is performed.²⁹ The candidate events is shown in the Dalitz plot in Fig. 5. There are no obvious structures, though the distribution is different from the pure $\omega p\bar{p}$ phase space distribution. The near-threshold $p\bar{p}$ invariant mass spectrum is also shown in Fig. 5, in which we can see no obvious enhancement as in $J/\psi \rightarrow \gamma p\bar{p}$. At the 95% confidence level, the upper limits on the product of branching fraction $J/\psi \rightarrow \omega X(p\bar{p}) \rightarrow \omega p\bar{p}$ are measured to be 3.7×10^{-6} and 3.9×10^{-6} with and without accounting for the Jülich FSI effect, respectively. As isospin for $J/\psi \rightarrow \gamma p\bar{p}$ and $\omega p\bar{p}$ should both favor $I = 0$, the non-observation of $X(p\bar{p})$ in $\omega p\bar{p}$ disfavors the pure FSI interpretation for the $p\bar{p}$ threshold enhancement in the decay $J/\psi \rightarrow \gamma p\bar{p}$.

3. Summary

The BESIII experiment addresses a wide range of topics in the field of hadron physics. At present BESIII has collected the world largest statistics on J/ψ , $\psi(3686)$, $\psi(3770)$ and $Y(4260)$ charmonium states. With these data samples, many precision measurements are being performed in the field of light hadron physics, charmonium spectroscopy and charmonium decays. Using a data sample of 0.5 fb^{-1} $Y(4260)$, a charged charmonium-like structure $Z_c(3900)$ is discovered. Since very recently, about 1.9 fb^{-1} $Y(4260)$ has been collected, which could give new insight in our understanding of this new discovered $Z_c(3900)$ and other mysterious XYZ states.

With the excellent performance of the accelerator and detector, more interesting results are expected.

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