Charmonium results from BES*

PING Rong-Gang(平荣刚)[1)]
(for BES collaboration)
Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China

Abstract Using $\sim 14\times10^6\,\psi(2S)$ and $\sim 58\times10^6$ J/ψ data collected at BES II /BEPC, the branching fraction of $\psi(2S)\to\Omega^-\bar{\Omega}^+$ is measured with about 5σ statistical significance. The Λ electric dipole and $\bar{\Lambda}$ decay parameter are studied using the decay $J/\psi\to\Lambda\bar{\Lambda}\to p\bar{p}\pi^+\pi^-$. Using $(106\pm3)\times10^6$ ψ(2S) decays collected at BESIII/BEPCII, we have obtained some interesting physics results. The branching fractions of $\chi_{cJ}\to\pi^0\pi^0$, ηη are measured with precision improved. The mass and width of $h_c(1^1P_1)$ state, together with the branching fractions of $Br(\psi(2S)\to\pi^0h_c)$ and $Br(h_c\to\gamma\eta_c)$ are the first measurements. Surprisingly, the decays of $\chi_{c1}\to\phi\phi$, ωω, and ωϕ are firstly observed in BESIII data.

Key words charmonium decays, J/ψ, χ_{cJ}, ψ(2S), BES II /BESIII experiment

PACS 13.20.Gd, 13.25.Gv, 14.20.Jn, 11.30.Er, 14.20.Jn

1 Introduction

The analyses reported in this talk were performed based on J/ψ and ψ(2S) events collected with the upgraded Beijing Spectrometer (BES II) detector [1] at the Beijing Electron-Positron Collider (BEPC), together with BESIII detector at the upgraded BEPC (BEPC II) in the year of 2009. The total decays of J/ψ and ψ(2S) are $(57.7\pm2.7)\times10^6$ and $(14.00\pm0.56)\times10^6$ at BES II , respectively, and $(106\pm3)\times10^6$ ψ(2S) decays at BESIII.

2 Preliminary results from BES II

2.1 $\psi(2S)\to\Omega^-\bar{\Omega}^+$

The study of ψ(2S) production in e^+e^- and its subsequent decay into two hadrons provides a test of the predictive power of QCD, including information on gluon spin, quark distribution amplitudes in baryon-antibaryon pairs, and total hadron helicity conservation. Many baryon pair decays of J/ψ or ψ(2S) have been studied by BES and CLEO Collaborations, but for $\psi(2S)\to\Omega^-\bar{\Omega}^+$, the previous measurement only yields an upper limit of 1.6×10^{-5} at confidence level of 90%. Using 14 million ψ(2S) events collected by BESII detector, 8 events are selected via the decay of $\psi(2S)\to\Omega^-\bar{\Omega}^+\to p\bar{p}K^+K^-\pi^+\pi^-$ with statistical significance of 5.3σ and 4.6σ for observing Ω^- and $\bar{\Omega}^+$, respectively. Fig. 1 shows the scatter plot of invariant mass $m_{\Lambda K^-}$ versus $m_{\bar{\Lambda}K^+}$. The branching fraction is determined to be $Br(\psi(2S)\to\Omega^-\bar{\Omega}^+)=(3.21\pm1.25_{\rm stat.}\pm0.86_{\rm syst.})\times10^{-5}$.

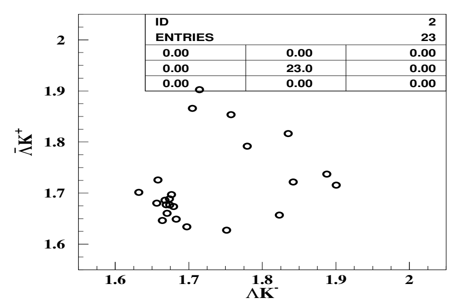

Fig. 1. A scatter plot of $m(\Lambda K^-)$ versus $m(\bar{\Lambda}K^+)$.

2.2 Measurement of $\bar{\Lambda}$ decay parameters

The nonleptonic decay of hyperon has long been known as an ideal laboratory to study the parity violation [2]. The precise measurement of the $\bar{\Lambda}$ decay

Received 25 January 2010

* Supported by National Natural Science Foundation of China (10491300, 10225524, 10225525, 10425523, 10625524, 10521003, 10821063, 10825524), Chinese Academy of Sciences (KJ 95T-03), 100 Talents Program of CAS (U-11, U-24, U-25), and Knowledge Innovation Project of CAS (U-602, U-34 (IHEP)), National Natural Science Foundation of China (10225522 (Tsinghua University))

1) E-mail: pingrg@mail.ihep.ac.cn

parameter plays an important role in CP test in Λ decays [3, 4]. Under CP transformation, the decay parameter satisfies $\alpha_\Lambda = -\alpha_{\bar{\Lambda}}$ if CP is conserved. If CP-odd observable is defined by $A_\Lambda = \frac{\alpha_\Lambda + \alpha_{\bar{\Lambda}}}{\alpha_\Lambda - \alpha_{\bar{\Lambda}}}$, then any non-zero value of A_Λ observed implies the evidence for CP asymmetry in Λ decays. Experimentally, searches for CP asymmetry in Λ nonleptonic decays have been previously performed at $p\bar{p}$ colliders by the R608 [5] and PS185 [6] Collaborations, and at a e^+e^- collider by DM2 Collaboration [7], but the precision of the measurements is limited by statistics.

Using 58 million J/ψ events collected by BESII detector, about 9000 events for $J/\psi \to \Lambda\bar{\Lambda}$ are selected [8]. Fitting to the joint angular distributions yields the angular distribution parameter $\alpha = 0.70 \pm 0.06$ for the decay of $J/\psi \to \Lambda\bar{\Lambda}$, and the $\bar{\Lambda}$ decay parameter $\alpha_{\bar{\Lambda}} = -0.755 \pm 0.083 \pm 0.063$, and the $CP-$odd observable is determined to be $A_\Lambda = -0.081 \pm 0.055 \pm 0.059$. Fig. 2 shows the fitted result (curve) of the joint angular distribution $\cos\theta_1 \cos\bar{\theta}_1 + \sin\theta_1 \sin\bar{\theta}_1 \cos(\phi_1+\phi_2)$, together with the data (error bar), where $(\theta_1,\ \phi_1)$ and $(\bar{\theta}_1,\ \bar{\phi}_1)$ are the helicity angles as defined in Refs. [8, 9] for the decay $\Lambda \to p\pi^-$ and $\bar{\Lambda} \to \bar{p}\pi^+$, respectively. The accuracy of this measurement still remains insufficient to observe CP violation at the level predicted by the standard model: $A_\Lambda = -2.10 \times 10^{-5}$ in Kobayashi-Maskawa model or $A_\Lambda = -1.10 \times 10^{-4}$ in Weinberg model [7].

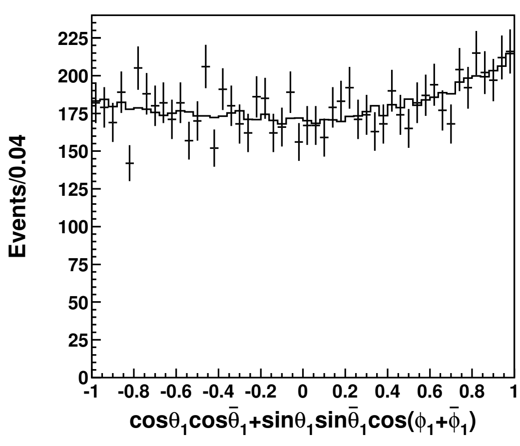

Fig. 2. Comparison between data (error bar) and fit results (histogram) of the distribution $\cos\theta_1 \cos\bar{\theta}_1 + \sin\theta_1 \sin\bar{\theta}_1 \cos(\phi_1 + \bar{\phi}_1)$.

2.3 Search for CP violation in $J/\psi \to \Lambda\bar{\Lambda}$

The electric dipole momentum (EDM) is believed as a promising source responsible for CP violation, which is suggested to search for as an evidence of new physics beyond standard model (SM). Stringent limits on the electric dipole moment of neutron [10] and electron [11] have been obtained. But the upper limits set for the electric dipole moment of Λ, Σ and other particles are fairly weak. $J/\psi \to \Lambda\bar{\Lambda}$ offers a good laboratory to measure the Λ electric dipole moment d_Λ and to test CP asymmetry due to the EDM [12, 13].

The CP-odd observable in $J/\psi \to \Lambda\bar{\Lambda}$ can be defined as [12, 13]

$$A_{CP} = \frac{N^+ - N^-}{N^+ + N^-}\ , \tag{1}$$

where $N^\pm$ indicates the number of events with sign $[\vec{P}\cdot(\vec{q}_1 \times \vec{q}_2)] = \pm$. $\vec{P}$ is the three-momentum of Λ and $\vec{q}_1(\vec{q}_2)$ is the three-momentum of $p(\bar{p})$ in the rest frame of $\Lambda(\bar{\Lambda})$. A non-zero A_{CP} may indicate CP violation in this decay.

With the assumption that the dominant contribution to the CP violation in $J/\psi \to \Lambda\bar{\Lambda}$ is made from the Λ electric dipole moment, d_Λ, one has a relationship between A_{CP} and d_Λ, i.e., $|A_{CP}| = (0.56 \sim 1.25) \times 10^{-2} d_\Lambda/(10^{-16}\ \text{ecm})$ [12]. The upper bound of d_Λ is 1.5×10^{-16} ecm [14] quoted from the measurement in [15]. If d_Λ indeed has a value close to its bound, A_{CP} can be expected as large as 10^{-2}. Therefore, an accurate measurement of A_{CP} can also be used to improve the upper bound of d_Λ.

Using 58 million J/ψ events collected by the BES II detector at the BEPC, the decay $J/\psi \to \Lambda\bar{\Lambda}$ is analyzed to test CP symmetry. Fig. 3 shows the comparison of A_{CP} distribution between data (error bar) and MC (histogram). The mean value of a CP -odd observable is measured to be $(-0.19 \pm 1.13 \pm 0.80) \times 10^{-2}$, consistent with the expectation of CP conserved. With the relationship given in Ref. [12], an upper limit of the electric dipole moment is determined to be 2.3×10^{-16} ecm at 95% confidence level.

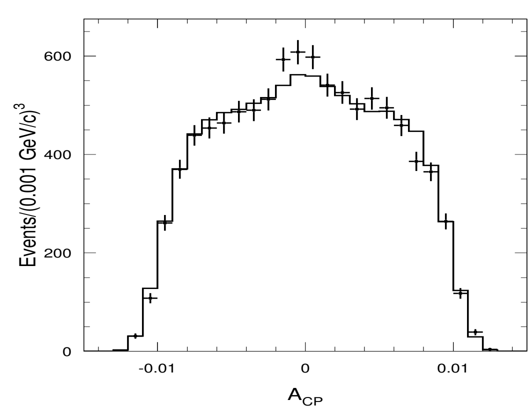

Fig. 3. Comparison of distribution of $\vec{P}_\Lambda \cdot (\vec{q}_1 \times \vec{q}_2)$ between data (error bar) and MC (histogram).

3 Preliminary results from BESIII

3.1 $\chi_{cJ} \to \pi^0\pi^0, \eta\eta$

As a ${}^3P_J$ states of $c\bar{c}$, χ_{cJ} decays into pseudoscalar meson pair have been studied in the framework of pQCD. It turns out that the measured decay width of $\chi_{cJ} \to$ PP (P: pseudoscalar) is hardly explained due to suppression predicted by the helicity selection rule here [16]. The color-octec decay mechanism for χ_{cJ} decays is proposed in recent years, and the decay widths of χ_{cJ} $(J = 0, 2) \to \pi^0\pi^0$, $\eta\eta$ are calculated based on this picture [17]. Experimentally, the decays of χ_{cJ} $(J = 0,\ 2) \to \pi^0\pi^0$, $\eta\eta$ are studied by CLEO Collaboration with 25.9 millon $\psi(2S)$ data collected at CESR [18], it was found that the measured branching fractions are larger than the previous PDG values (over 2σ difference).

Using 106×10^6 $\psi(2S)$ sample collected at BESIII detector, the decays $\chi_{cJ} \to \pi^0\pi^0$, $\eta\eta$ $(J = 0, 2)$ are studied via the decay $\psi(2S) \to 5\gamma$. The two π^0/ηs are reconstructed with four photons selected by requiring the $\sqrt{P_1^2(\pi^0/\eta) + P_2^2(\pi^0/\eta)}$ having a minimum value in all possible photon's combinations, where $P_i(\pi^0/\eta) = (M_{\gamma\gamma} - M_{\pi^0/\eta})/\sigma_{\gamma\gamma}$, and $\sigma_{\gamma\gamma}$ is the mass resolution for two photons.

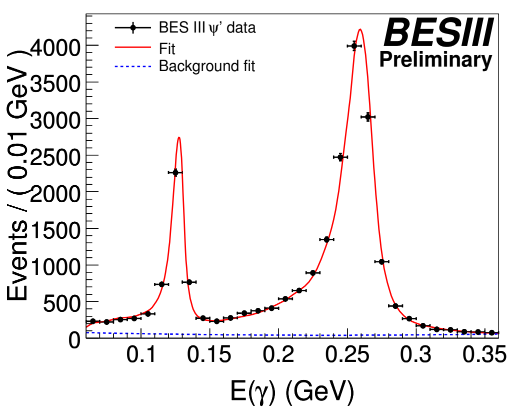

Fig. 4. The radiative photon energy distribution for $\psi(2S) \to \gamma\chi_{cJ}$, $\chi_{cJ} \to \pi^0\pi^0$. The dots with error bars are data. The solid curve is the fitted result as described in text, and the dash line is the background.

The photon spectrum in the decay $\psi(2S) \to \gamma\chi_{cJ}$ for the channel $\chi_{cJ} \to \pi^0\pi^0$ and $\chi_{cJ} \to \eta\eta$ are shown in Figs. 4 and 5, respectively. Where the χ_{c0} and χ_{c2} signals are clearly observed. As expected, the χ_{c1} state is not observed due to the spin-parity violation for its decays into a pseudoscalar pair. A fit to the photon spectrum with the χ_{cJ} MC shape for signal plus a 2nd-order Chebychev polynomial for backgrounds (dash curve) is performed. The branching fractions are measured to be $Br(\chi_{c0} \to \pi^0\pi^0) = (3.25\pm0.03)\times10^{-3}$, $Br(\chi_{c2} \to \pi^0\pi^0) = (8.6\pm0.2)\times10^{-4}$, $Br(\chi_{c0} \to \eta\eta) = (3.1 \pm 0.1) \times 10^{-3}$ and $Br(\chi_{c2} \to \pi^0\pi^0) = (5.9 \pm 0.5) \times 10^{-4}$. Here the errors are only statistical ones.

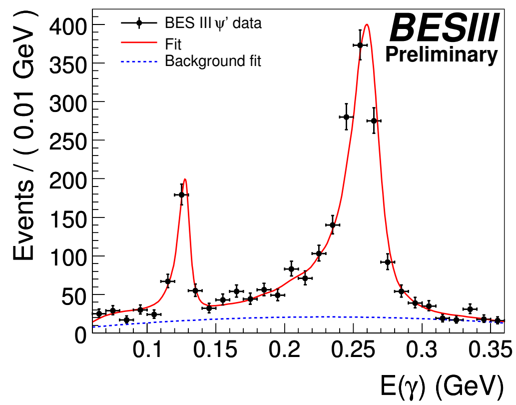

Fig. 5. The radiative photon energy distribution for $\psi(2S) \to \gamma\chi_{cJ}$, $\chi_{cJ} \to \eta\eta$. The dots with error bars are data. The solid curve is the result result as described in text, and the dash line is background.

3.2 Measurement of the $h_c({}^1P_1)$ state

Charmonium spectroscopy and transitions between them have played an important role to understand the quark-antiquark ($Q\bar{Q}$) interaction of quantum chromodynamics (QCD) in particle physics. The P-wave singlet charmonium state $h_c({}^1P_1)$ is particularly significant since the triplet-singlet hyperfine splitting $\Delta M_{hf} \equiv \langle M(1^3P_J)\rangle - \langle M(1^1P_1)\rangle$ is generally believed as an ideal tool to test the spin dependence and spatial behavior of the $Q\bar{Q}$ force, where $\langle M(1^3P_J)\rangle = [M(\chi_{c0}) + 3M(\chi_{c1}) + 5M(\chi_{c2})]/9 = 3525.30 \pm 0.04$ MeV [19]. Lattice QCD [20] and relativistic calculations [21] predict the hyperfine splitting ΔM_{hf} less than a few MeV. Recently, the h_c state has been identified by CLEO [22] Collaboration. Their measurements yield $m(h_c) = 3525.28 \pm 0.19(\text{stat.}) \pm 0.12(\text{syst.})$ MeV, and $\mathcal{B}(\psi(2S) \to \pi^0 h_c) \times B(h_c \to \gamma\eta_c) = (4.19 \pm 0.32 \pm 0.45) \times 10^{-4}$. A less convincing h_c signal was also seen in $p\bar{p} \to h_c \to \gamma\eta_c$ by E835 Collaboration [23]. They measured the mass of $m(h_c) = 3525.8 \pm 0.2 \pm 0.2$ MeV with a width $\Gamma_{h_c} \leqslant 1$ MeV. The CLEO measurement of h_c mass yields the mass splitting $\Delta M_{hf} = +0.02\pm0.19\pm0.13$ MeV, whose central value agrees with the expectation of perturbative QCD calculations [24], $m(h_c) > \langle m(1^3P_J)\rangle$, but with large uncertainty to distinguish lattice QCD prediction $m(h_c) < \langle m(1^3P_J)\rangle$ [20]. The measurement of branching fraction $\psi(2S)\to\pi^0 h_c$ is urgent to determine the absolute decay rate of h_c particle produced in $\psi(2S)$ decays, e.g. h_c hadronic decays [25]. A theoretical calculation based on the QCD multipole expansion [26] predicts the branching fraction of $B(\psi(2S)\to\pi^0 h_c)=(4.8\sim 14.4)\times 10^{-4}$, along with the prediction of total decay width $\Gamma(h_c)=(0.51\pm 0.01)$ MeV. However, to measure the absolute branching fraction for $\psi(2S)\to\pi^0 h_c$ by observing the π^0 recoil mass spectrum needs high statistics of $\psi(2S)$ data sample and good detector performance for detecting the soft photons. They are not measured till now.

Figure 6 shows the distribution of π^0 recoil mass to search for h_c signals in the sequential decay $\psi(2S)\to\pi^0 h_c$, $h_c\to\gamma\eta_c$. The photon in the E1 transition $h_c\to\gamma\eta_c$ is used as an E1-tag of this decay, which allows to reconstruct η_c inclusively. One performs a fit with a Breit-Wigner convoluted with the instrument resolution function obtained in MC simulation for signal plus a background shape obtained using the generic $\psi(2S)$ MC sample of 100 million decays. The fit yields the mass and width of h_c, i.e., $M(h_c)=3525.16\pm 0.16\pm 0.10$ MeV and $\Gamma(h_c)=0.89\pm 0.57\pm 0.23$ MeV, respectively. The product branching fraction is calculated to be $Br(\psi(2S)\to\pi^0 h_c)\times Br(h_c\to\gamma\eta_c)=(4.68\pm 0.29_{\rm stat.})\times 10^{-4}$.

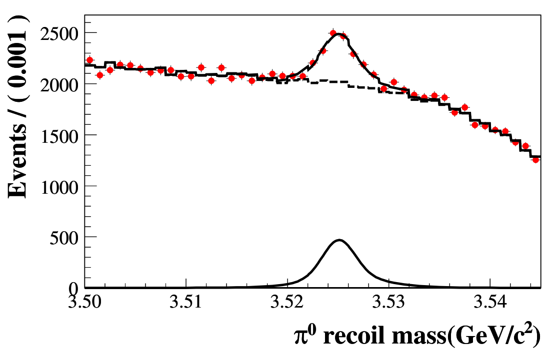

Fig. 6. π^0 recoil mass (points with error bar) and fitted results (curve) for the analysis of E1 tag process $\psi(2S)\to\pi^0 h_c$, $h_c\to\gamma\eta_c$.

To measure the branching fraction $\psi(2S)\to\pi^0 h_c$, one needs to look for h_c candidates without the E1-tag requirement. Fig. 7 shows the π^0 recoil mass spectrum in the h_c mass region, where h_c is allowed to decay into anything. A fit is performed to the distribution of π^0 recoil mass with a Breit-Wigner convoluted with a mass resolution function for signals plus a 4-th order of Chebychev polynomial for backgrounds. The branching fraction is determined to be $Br(\psi(2S)\to\pi^0 h_c)=(8.42\pm 1.29_{\rm stat.})\times 10^{-4}$. Combined with the result of E1-tag process, one obtains $Br(h_c\to\gamma\eta_c)=(55.7\pm 6.3_{\rm stat.})\%$.

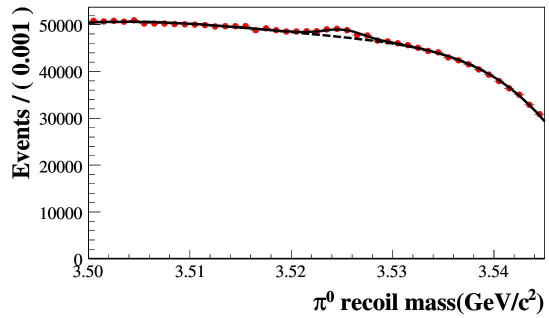

Fig. 7. π^0 recoil mass (points with error bar) and fitted results (curve) for the analysis of $\psi(2S)\to\pi^0 h_c$.

3.3 Observation of $\chi_{cJ}\to\phi\phi$, $\omega\omega$, and $\omega\phi$

χ_{cJ} decays are believed as an ideal laboratory to test QCD theory and to test the χ_{cJ} decay mechanism based on color octet theory [27]. For the decays of $\chi_{cJ}\to$ VV (V: vector meson, $J=0,\ 2$), the measured branching fractions are still not well understood in QCD theory. For example, the decays of $\chi_{cJ}\to\omega\omega$, $\phi\phi$ ($J=0,\ 2$) are suppressed due to the helicity selection rule (HSL) [28]. However, the BES II measurements show that the χ_{cJ} have a larger branching fractions to decay into these final states [29, 30]: $Br(\chi_{cJ}\to\omega\omega)=(2.3\pm 0.7)\times 10^{-3}$ and $Br(\chi_{cJ}\to\phi\phi)=(9.3\pm 2.0)\times 10^{-4}$.

For the decays of $\chi_{c1}\to\omega\omega,\phi\phi$, they are expected to be highly suppressed due to the requirement of the identical particle symmetry. If $\omega\omega$ and $\phi\phi$ are regarded as identical particles, then only D-wave of orbital momentum is allowed to occur in χ_{c1} decays. For the decay of $\chi_{cJ}\to\omega\phi$, it is the doubly OZI suppressed decay, and they are still not observed in experiment. Surprisingly, these decays are observed at BESIII data.

Figure 8 shows the mass spectrum of $\phi\phi$ reconstructed via the decay $\psi(2S)\to\gamma 2(K^+K^-)$. In the scatter plot of the mass $m_{K^+K^-}$ versus other two kaon mass $m_{K^+K^-}$, the $\phi\phi$ signals are clearly seen. After requiring the two ϕ selection, the χ_{cJ} ($J=0,\ 1,\ 2$) signals are clearly seen in the distribution of invariant mass $m_{\phi\phi}$. The contribution from nonresonance decays of $\chi_{cJ}\to 2(K^+K^-)$ and $\chi_{cJ}\to\phi K^+K^-$ can be estimated with the ϕ sidebands as shown in Fig. 8 (shaded histogram). The significantly net signals for $\chi_{c1}\to\phi\phi$ are observed.

Figure 9 shows the mass spectrum of $\omega\omega$ reconstructed via the decay $\psi(2S) \to 5\gamma 2(\pi^+\pi^-)$. Where the two π^0 candidates are reconstructed with the four photons with the masses closest to the two π^0 masses, i.e. $\sqrt{(M_{\gamma\gamma}^{(1)} - M_{\pi^0})^2 + (M_{\gamma\gamma}^{(2)} - M_{\pi^0})^2}$, then a ω is reconstructed with a combination of $\pi^+\pi^-\pi^0$ selected by minimizing $|M_{\pi^+\pi^-\pi^0} - M_\omega|$. The rest combination of $\pi^+\pi^-\pi^0$ is regarded as a candidate of other ω signal. After requiring the two ωs falling into the ω mass window $|M_{\pi^+\pi^-\pi^0} - M_\omega| < 0.04$ GeV, the χ_{cJ} $(J = 0,1,2)$ signals are clearly observed at the mass spectrum $m_{\omega\omega}$. The backgrounds from $\psi(2S) \to \pi^+\pi^- J/\psi \to 5\gamma 2(\pi^+\pi^-)$ are rejected by requiring $|M_{\pi^+\pi^-}^{\rm recoil} - M_{J/\psi}| > 0.008$ GeV, and the nonresonance contribution is estimated via the sidebands of ω mass windows.

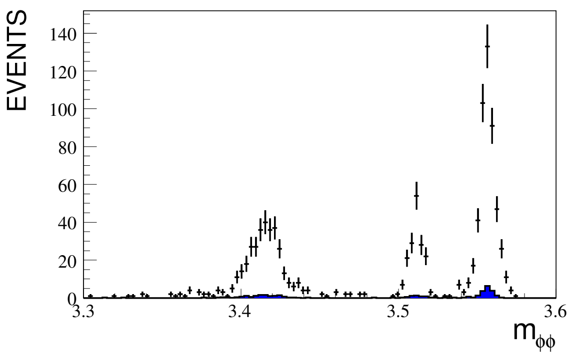

Fig. 8. The invariant mass distribution of $m_{\phi\phi}$ in the BESIII data with two ϕs reconstructed from $2(K^+K^-)$ (points with error bar), and shaded histogram is estimated with ϕ sidebands.

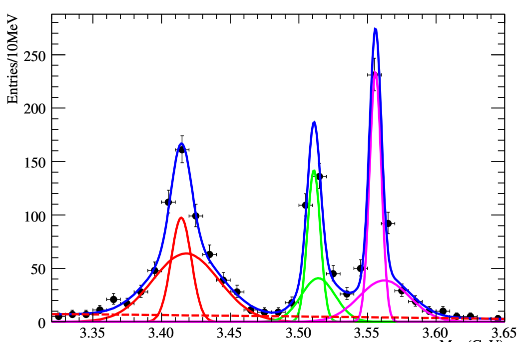

Fig. 9. The invariant mass distribution of $m_{\omega\omega}$ for data (error bar), and the blue curve is fitted result with double Gaussian distributions (in red, green and crimson color) plus backgrounds (dash line).

Figure 10 shows the mass spectrum of $\phi\phi$ reconstructed via the decay $\psi(2S) \to 3\gamma K^+K^-\pi^+\pi^-$, where a ϕ is reconstructed with the decay $\phi \to K^+K^-$, while another ϕ is reconstructed with the decay $\phi \to \pi^+\pi^-\pi^0$. Here the π^0 is reconstructed with two photons out of three selected photons by minimizing the $\sqrt{(M_{\gamma\gamma} - M_{\pi^0})^2 - (M_{\gamma\gamma\pi^+\pi^-} - M_\phi)^2}$. After requiring the two ϕ candidates falling into the mass widows $|M_{\pi^+\pi^-\pi^0} - M_\phi| < 0.03$ GeV and $|M_{K^+K^-} - M_\phi| < 0.015$ GeV, the χ_{cJ} $(J = 0,\ 1,\ 2)$ signals are clearly observed at the mass spectrum $m_{\phi\phi}$. The non-ϕ's contribution are studied with the ϕ sidebands.

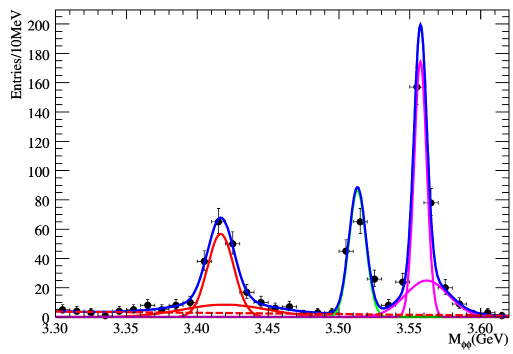

Fig. 10. The invariant mass distribution of $m_{\phi\phi}$ for data (error) and fitted results (blue curve) with double Gaussian distributions plus backgrounds (dash line); one ϕ is reconstructed from $\phi \to K^+K^-$, and another ϕ is reconstructed from $\phi \to \pi^+\pi^-\pi^0$.

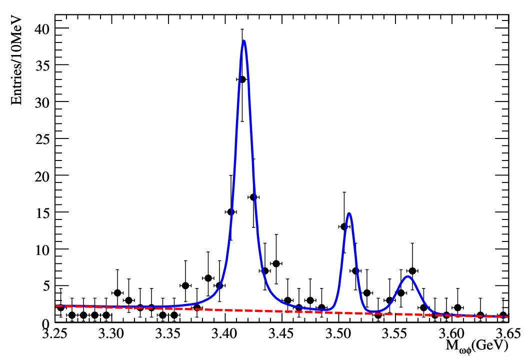

Fig. 11. The invariant mass distribution of $m_{\omega\phi}$ for data (error bar); the curve is the fitted results with Breit-Wigner convoluted with mass resolution for signal plus background (dash line).

Figure 11 shows the mass spectrum of $\omega\phi$ reconstructed via the decay $\psi(2S) \to 3\gamma K^+K^-\pi^+\pi^-$, where a ϕ is reconstructed with the decay $\phi \to K^+K^-$, while ω is reconstructed with the decay $\omega \to \pi^+\pi^-\pi^0$. Here the π^0 is reconstructed with two photons out of the three selected photons by minimizing the $\sqrt{(M_{\gamma\gamma}-M_{\pi^0})^2-(M_{\gamma\gamma\pi^+\pi^-}-M_{\omega})^2}$. After requiring the mass widows $|M_{\pi^+\pi^-\pi^0}-M_{\omega}|<0.04$ GeV and $|M_{K^+K^-}-M_{\phi}|<0.015$ GeV, the χ_{cJ} $(J=0,\ 1,\ 2)$ signals are clearly observed at the mass spectrum $m_{\phi\phi}$. The non-ϕ/ω's contribution are studied with the ϕ/ω sidebands.

4 Summary

Using $\sim 14\times10^6\,\psi(2S)$ and $\sim 58\times10^6\,J/\psi$ data collected at BESII/BEPC, the branching fraction of $\psi(2S)\to\Omega^-\bar{\Omega}^+$ is firstly measured with about 5σ statistical significance. The Λ electric dipole and $\bar{\Lambda}$ decay parameter are studied using the decay $J/\psi\to\Lambda\bar{\Lambda}\to p\bar{p}\pi^+\pi^-$.

Using $(106\pm3)\times10^6$ $\psi(2S)$ decays collected at BESIII/BEPCII, we have obtained some interesting physics results. The preliminary branching fractions of $\chi_{cJ}\to\pi^0\pi^0$, $\eta\eta$ are measured with precision improved. The mass and width of $h_c(1^1P_1)$ state, together with the branching fractions of $Br(\psi(2S)\to\pi^0h_c)$ and $Br(h_c\to\gamma\eta_c)$ are the first measurements. Surprising, the decays of $\chi_{c1}\to\phi\phi$, $\omega\omega$, and $\omega\phi$ are firstly observed in BESIII data. The measurement of branching fraction for these decay is on going, and the results will come soon.

The BES Collaboration thanks the staff of BEPC and computing center for their hard efforts.

References

1 Bai J Z et al (BES collaboration). Nucl. Instrum. Methods A, 2001, **458**: 627
2 Lee T D, YANG C N. Phys. Rev., 1957, **108**: 1645 Lee T D, Steinberger J, Feinberg G et al. Phys. Rev., 1957, **106**: 1367
3 Chan A W et al. Phys. Rev. D, 1988, **58**: 072002
4 Pais A. Phys. Rev. Lett., 1959, **3**: 242
5 Chauvat P et al. Phys. Lett. B, 1985, **163**: 273
6 Barnes P D et al. Phys. Rev. C, 1996, **54**: 1877
7 Tixier M H et al. Phys. Lett. B, 1988, **212**: 523
8 Ablikim M et al (BES collaboration). arXiv:0911.2972v1 [hep-ex]
9 CHEN H, PING R G. Phys. Rev. D, 2007, **76**: 036005
10 Smith K F et al. Phys. Lett. B, 1990, **234**: 234
11 Adbullah K et al. Phys. Rev. Lett., 1990, **65**: 2347
12 HE X G, MA J P, McKellar B. Phys. Rev. D, 1993, **47**: R1744
13 HE X G, MA J P, McKellar B. Phys. Rev. D, 1994, **49**: 4548
14 Amsler C et al (Particle Data Group). Phys. Lett. B, 2008, **667**: 1
15 Pondrom L, Handler R, Sheaff M. Phys. Rev. D, 1981, **23**: 814
16 Jones H F, Wyndham J. Nucl. Phys. B, 1982, **195**: 222
17 Bolz J et al. Phys. Lett. B, 1997, **392**: 198–206; hep-ph/9610265; Eur. Phys. J. C, 1998, **2**: 705–719; hep-ph/9704378
18 Asner D M et al (CLEO collaboration). Phys. Rev. D, 2009, **79**: 072007
19 Amsler C et al. Phys. Lett. B, 2008, **667**: 1
20 Manke T et al. Phys. Rev. D, 2000, **62**: 114508; Okamoto M et al. Phys. Rev. D, 2002, **65**: 094508
21 Ebert D, Faustov R N, Galkin V O. Phys. Rev. D, 2003, **67**: 014027. CLEO collaboration. Phys. Rev. D, 2005, **72**: 092004
22 Dobbs S et al (CLEO collaboration). Phys. Rev. Lett., 2008, **101**: 182003
23 Andreotti M et al (E835 collaboration). Phys. Rev. D, 2005, **72**: 032001
24 Pantaleone J, Tye S H H. Phys. Rev. D, 1998, **37**: 3337
25 Adams G S et al (CLEO collaboration). Phys. Rev. D, 2009, **80**: 051106
26 KUANG Y P, TUAN S F, YAN T M. Phys. Rev. D, 1988, **37**: 1210; KUANG Y P. Phys. Rev. D, 2002, **65**: 094024
27 Bolz J, Kroll P, Schuler G A. Eur. Phys. J. C, 1998, **2**: 705–719; Wong S M H. Eur. Phys. J. C, 2000, **14**: 643–671
28 Brodsky S J, Lepage G P. Phys. Rev. D, 1981, **24**: 2848
29 Ablikim M et al (BES collaboration). Phys. Lett. B, 2006, **642**: 197
30 Ablikim M et al (BES collaboration). Phys. Lett. B, 2005, **630**: 7