Light hadron spectroscopy at BESIII

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Abstract. Light hadron spectroscopy is one of the most important physics goals of high statistics of charmonium decays collected at BESIII which provide an excellent place for hunting gluonic excitations and studying strangeonium. In this proceeding, we will introduce two analyses for gluonic states study on $\eta(1405)/\eta(1475)$ puzzle, $X(1835)$ and exotic states and two analyses for strangeonium(like) states study on $Y(2175)$ and Z_s state.

1 Introduction

Quantum chromodynamics(QCD) is one of the fundamental theories in modern high energy physics. Light hadron spectroscopy plays a crucial role in understanding and examining the QCD theory in non-perturbative energy region. BESIII has collected 1.31×10^9 J/ψ events and 4.48×10^8 $\psi(3686)$ events since 2009 which gives us a good opportunity to study light hadron spectroscopy.

2 Recent results on gluonic states

2.1 Observation of $\eta(1475)$ and $X(1835)$ in $J/\psi \to \gamma\gamma\phi$

In 1990, Mark III reported two pseudoscalars in 1400 MeV/c^2 region [1]. This results were confirmed by Obelix [2]. However, L3 observed $\eta(1475) \to K\bar{K}\pi$ in two-photon collisions but no observation of $\eta(1405)$ [3]. In 2005, CLEO published negative results on both states [4]. In 2012, BESIII observed $\eta(1405) \to f_0(980)\pi^0$ with narrow $f_0(980)$ and large isospin violation [5]. To explain the anomalies, Triangle Singularity was proposed which indicates $\eta(1405)$ and $\eta(1475)$ could be one state appeared as different line shape in different channel [6].

The $X(1835)$ was first observed by the BESII experiment in the $\pi^+\pi^-\eta$ [7] invariant mass spectrum and was confirmed with higher statistical significance by the BESIII [8]. Its J^{pc} was measured to be 0^{-+} in the $K^0_S K^0_S \eta$ invariant mass spectrum by BESIII [9]. Furthermore, a recent BESIII result observes an anomalous line shape of the $X(1835)$ near the $p\bar{p}$ threshold in the decay $J/\psi \to \gamma\pi^+\pi^-\eta'$ [10]. Until now, the nature of the $X(1835)$ is still an open question.

As a flavor filter, $J/\psi \to \gamma\gamma\phi$ was analyzed with 1.311 billion J/ψ data sample collected since 2009. Two structures around 1.47 and 1.85 GeV/c^2 were observed in $\gamma\phi$ invariant mass.

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The fitting results are shown in Fig. 1 (a), (b). A fit on the polar angle distribution of the radiative photon shown in Fig. 1 (c), (d) favors $J^{pc} = 0^{-+}$ assignment for the two resonances. The obtained mass, width and J^{pc} supports the two observed resonances are $\eta(1475)$ and $X(1835)$, respectively. The observation of $\eta(1475)$ and $X(1835)$ decaying into $\gamma\phi$ suggest these two states contain a sizable $s\bar{s}$ component. For the $\eta(1405)/\eta(1475)$ puzzle, in the case of one state assumption, the branching fraction ratio of $(Br_{\eta(1475/1475)\to\gamma\rho} : Br_{\eta(1475/1475)\to\gamma\phi})$ is calculated to be $(11.10 \pm 3.50 : 1)$ for the case of destructive interference and $(7.53 \pm 2.49 : 1)$ for constructive interference. The prediction of partial width ratio is 3.8 : 1 in Ref. [11]. For the case of two state assumption, the observation of the $\eta(1475)$ decaying into $\gamma\phi$ final state suggests that the $\eta(1475)$ should be the radial excitation of the η' [12].

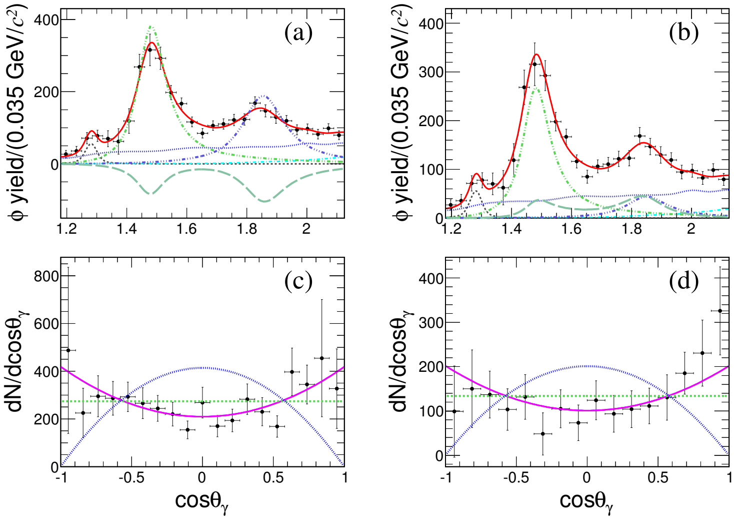

Figure 1. Fits to the $M_{\gamma\phi}$ distributions for the case of (a) constructive and (b) destructive interference. Fits to the $\cos\theta_\gamma$ distributions for invariant mass for (c) in [1.4,1.6] GeV/c^2 region and (d) in [1.75, 1.9] GeV/c^2 region.

2.2 Amplitude Analysis of $\chi_{c1} \to \pi^+\pi^-\eta$ decays

Several candidates with $J^{pc} = 1^{-+}$, decaying into different final states, such as $\eta\pi$, $\eta'\pi$, $f_1(1270)\pi$ and so on, have been reported by various experiments [13]. The lightest exotic meson $\pi_1(1400)$ is only reported in the $\eta\pi$ final state and the most promising $J^{pc} = 1^{-+}$ $\pi_1(1600)$ is studied by CLEO-c which could also couple to the $\eta\pi$ [14].

Using 448.0×10^6 $\psi(3686)$ events collected with the BESIII detector, an amplitude analysis is performed for $\psi(3686) \to \gamma\chi_{c1}, \chi_{c1} \to \eta\pi^+\pi^-$ decays which is suitable for studying the production of exotic mesons with $J^{pc} = 1^{-+}$. In this analysis, the most dominant two-body structure is $a_0(980)^\pm\pi^\mp$; $a_0(980)^\pm \to \eta\pi^\pm$. A significant nonzero $a_0(980)$ coupling to the $\eta'\pi$ channel is measured with a significance of 8.9σ. We also observe $\chi_{c1} \to a_2(1700)\pi$ production for the first time, with a significance larger than 17σ. This may help in listing the $a_2(1700)$ as an established resonance by the PDG [15]. We examine the production of exotic mesons that might be expected in the $\chi_{c1} \to \eta\pi\pi$ decays and the upper limits for the branching fractions $\chi_{c1} \to \pi_1(1400/1600/2015)^\pm\pi^\mp$, with subsequent $\pi_1(X)^\pm \to \eta\pi^\pm$ decay, are determined at 90% C.L.. The results are shown in Fig. 2 and Tab. 1.

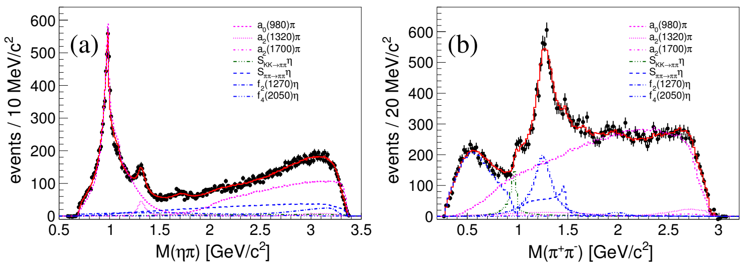

Figure 2. Projections in the (a) $\eta\pi$ and (b) $\pi^+\pi^-$ invariant mass from data, compared with our base-line fit (solid curve) and corresponding amplitudes (various dashed and dotted lines).

Table 1. Fractional intensities $\mathcal{F}$, significances and U.L. for exotic states.

Exotic candidates	$\mathcal{F}$ [%]	Significance [σ]	U.L. [90% C.L.]
$\pi_1(1400)^+\pi^-$	0.58±0.20	3.5	< 0.046
$\pi_1(1600)^+\pi^-$	0.11±0.10	1.3	< 0.015
$\pi_1(2015)^+\pi^-$	0.06±0.03	2.6	< 0.008

3 Recent results on strangeonium(like) states

3.1 Observation of $e^+e^- \to \eta Y(2175)$ at center-of-mass energies above 3.7 GeV

The $Y(2175)$ was first observed by the BaBar collaboration [16] via the initial-state-radiation (ISR) process $e^+e^- \to \gamma_{\rm ISR}\phi f_0(980)$ and later confirmed by the Belle collaboration [17], BESII and BESIII collaborations [18, 19]. Ref. [20] predicts the existence of a sharp peaking structure (Z_{s1}) close to the $K\bar{K}^*$ threshold and a broad structure (Z_{s2}) close to the $K^*\bar{K}^*$ threshold in the $\pi\phi$ mass spectrum. We can search $Z_s \to \pi^\pm\phi$ process analogied to $Z_c(3900) \to \pi^\pm J/\psi$ process.

In this analysis, $e^+e^- \to \eta Y(2175)$ was studied at higher energy up to 4.6 GeV accumulated at BESIII [21]. The $Y(2175)$ is observed with a joint statistical significance lager than 10 σ using a simultaneous fit in the invariant mass spectrum of $\phi f_0(980)$ for the seven data samples. We also searched for the Z_s in the $\phi\pi$ mass spectrum. No significant Z_s signal can be seen at the expected positions.

3.2 Search for strangeonium-like states Z_s decaying into $\phi\pi$ at 2.125 GeV

Using a data sample of e^+e^- collision data corresponding to an integrated luminosity of 108 pb^{-1} collected with the BESIII detector at a center-of-mass energy of 2.125 GeV, we study the process $e^+e^- \to \phi\pi\pi$, and search for a strangeonium-like structure Z_s decaying into $\phi\pi$. No signal is observed in the $\phi\pi$ mass spectrum. A PWA analysis is performed and upper limits on the cross sections for Z_s production at the 90% confidence level are determined by introducing an additional Z_s component in the amplitude analysis. We performed the alternative amplitude analysis by assuming $J^P = 1^+$ and $J^P = 1^-$ for Z_s to explore its contribution to the data. The upper limits on the differential cross sections of Z_s production as a function of the assumed mass of Z_s with different width scenario are estimated at 90% C.L. which are displayed in Fig. 3.

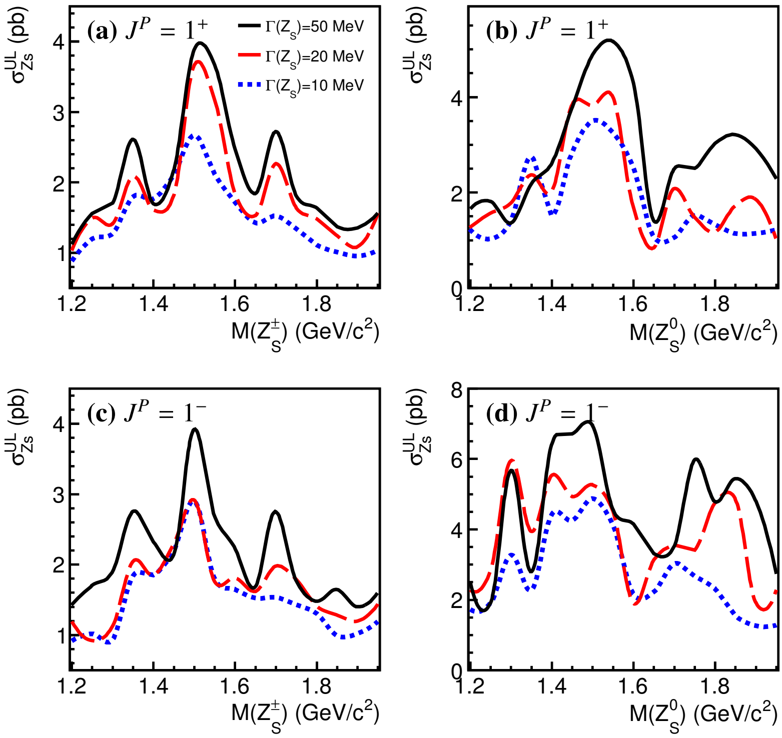

Figure 3. The upper limits at 90% C.L. on the differential cross sections of Z_s as a function of assumed signal peak mass for the cases (a) $J^P = 1^+$ of $Z_s^\pm$, (b) $J^P = 1^+$ of Z_s^0, (c) $J^P = 1^-$ of $Z_s^\pm$, and (d) $J^P = 1^-$ of Z_s^0. The dotted, dashed and solid lines are the results of Γ=10, 20, and 50 MeV, respectively.

4 Summary

With the largest J/ψ and $\psi(3686)$ data sample in the world, the BESIII collaboration has contributed a lot in light hadron spectroscopy. We conducted a series of study on the gluonic states and strangeonium(like) states. Several recent results of light hadron spectroscopy are reported. With the high statistics data accumulated at the BESIII detector, more interesting results are expected in the future.

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