Recent results of light hadron spectroscopy from BESIII

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We present a selection of recent results on light hadron spectroscopy from the BESIII collaboration. The topics include the full partial wave analysis on J/ψ radiative decays, including $J/\psi \rightarrow \gamma\eta\eta$ and $\gamma\omega\phi$. Besides, we also cover the topics about the resonance $Y(2175)$ and $\eta(1405)$.

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1. Introduction

According to lattice QCD predictions,^{1,2} the lowest mass glueball with $J^{PC} = 0^{++}$ is in the mass region from 1.5 to 1.7 GeV/ c^2 . Radiative J/ψ decay is a gluon-rich process and has long been regarded as one of the most promising hunting grounds for glueballs. In particular, for a J/ψ radiative decay to two pseudoscalar mesons, it offers a very clean laboratory to search for scalar and tensor glueballs because only intermediate states with $J^{PC} = \text{even}^{++}$ are possible.

Around 1.7 GeV/ c^2 , three resonances have been observed in experiments, while Quark Model only allows one meson in this mass range. By now, it is confusing for us that whether the $f_0(1710)$, $f_0(1790)$ and $X(1810)$ are the same resonance.

Since the discovery of the $Y(2175)$,³ noted as $\phi(2170)$ in the Particle Data Group (PDG 2012),⁴ it stimulates many theoretical speculations, including the $s\bar{s}$ -gluon hybrid,⁵ excited ϕ state,⁶ tetraquark state,⁷ as well as the $\Lambda\bar{\Lambda}$ bound state.^{8,9} In addition to the confirmation in the initial-state-radiation (ISR) process,^{10,11} the $Y(2175)$ was also observed in the decay $J/\psi \rightarrow \phi f_0(980)\eta$, $f_0(980) \rightarrow \pi^+\pi^-$ with low statistics, using the 58 million J/ψ events accumulated at the BESII detector.¹²

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Apart from the study of $Y(2175)$, the $J/\psi \rightarrow \phi\pi^+\pi^-\eta$ decay offers us an unique opportunity to investigate the properties of $f_1(1285)$ and $\eta(1405)$. The $f_1(1285)$ is usually considered as a member of the axial vector meson nonet, however it gets complication with the observation of the $\eta(1295)$.¹³ Because both the $f_1(1285)$ and $\eta(1295)$ were seen in the fixed target experiments, but the $\eta(1295)$ was not evident in central production, $\gamma\gamma$ collisions and J/ψ decays as we expected. Therefore one speculated that either some of the $f_1(1285)$ observations are the mixture of both,¹⁴ or the $\eta(1295)$ does not exist. As one of the two pseudoscalar components around $1.44 \text{ GeV}/c^2$ (so-called E/ι), $\eta(1405)$ was once regarded as a glueball candidate since it was copiously produced in J/ψ radiative decay¹⁵ and there was only an upper limit from the $\gamma\gamma$ collisions.¹⁶ But this viewpoint changed when it was also observed in the untagged $\gamma\gamma$ collisions,¹⁷ J/ψ hadronic decays and its radiative decay modes were observed.¹⁸⁻²¹

In this talk, the recent results on the scalar glueball candidates and $Y(2175)$ are present based on a sample of 2.25×10^8 J/ψ collected with the BESIII detector at BEPCII.

2. Highlights from BESIII

2.1. Study of scalars

2.1.1. Partial wave analysis (PWA) of $J/\psi \rightarrow \gamma\eta\eta$

Based on a sample of 2.25×10^8 J/ψ events collected with the BESIII detector at BEPCII, a full partial wave analysis on $J/\psi \rightarrow \gamma\eta\eta$ was performed using the relativistic covariant tensor amplitude method,²² with two η 's decaying into $\gamma\gamma$. Figs. 1(a) and 1(b) show the Dalitz plot of $J/\psi \rightarrow \gamma\eta\eta$ and $\eta\eta$ invariant mass spectrum, where clear diagonal bands, which correspond to the structures observed in the $\eta\eta$ invariant mass spectrum, can be seen in the Dalitz plot for the selected $J/\psi \rightarrow \gamma\eta\eta$ candidate events. The shaded histograms in in Fig. 1(b) are non- η background estimated by η sideband, and the background are subtracted from the log likelihood in the partial wave analysis. Comparisons between data and PWA fit projections are shown in Figs. 1(c)-1(f).

The results show that the dominant 0^{++} and 2^{++} components are from the $f_0(1710)$, $f_0(2100)$, $f_0(1500)$, $f_2'(1525)$, $f_2(1810)$ and $f_2(2340)$. The resonance parameters and branching fractions are also presented as shown in Tab. 1. The scalar contributions are mainly from $f_0(1500)$, $f_0(1710)$ and $f_0(2100)$, while no evident contributions from $f_0(1370)$ and $f_0(1790)$ are seen. Recently, the production rate of the pure gauge scalar glueball in J/ψ radiative decays predicted by the lattice QCD¹ was found to be compatible with the production rate of J/ψ radiative decays to $f_0(1710)$; this suggests that $f_0(1710)$ has a larger overlap with the glueball compared to other glueball candidates (eg. $f_0(1500)$). In this analysis, the production rate of $f_0(1710)$ and $f_0(2100)$ are both about one order of magnitude larger than that of the $f_0(1500)$ and no clear evidence is found for $f_0(1370)$, which are both consistent with, at least not contrary to, lattice QCD predictions.

Fig. 1. (a) Dalitz plot. (b) The invariant mass spectrum of $\eta\eta$. The dots with error bars are data, and the shaded histogram is background estimated from η sidebands. (c) the invariant mass spectrum of $\eta\eta$, (e)-(f) the polar angle of the radiative photon in the J/ψ rest frame and η in the $\eta\eta$ helicity frame, and (e) the azimuthal angle of η in the $\eta\eta$ helicity frame. The black dots with error bars are data with background subtracted, and the solid histograms show the PWA projections.

Table 1. Summary of the PWA results, including the masses and widths for resonances, branching ratios of $J/\psi \rightarrow \gamma X$, as well as the significance. The first errors are statistical and the second ones are systematic. The statistic significances here are obtained according to the changes of the log likelihood.

Resonance	Mass(MeV/c ²)	Width(MeV/c ²)	$B(J/\psi \rightarrow \gamma X \rightarrow \gamma\eta\eta)$	Significance
$f_0(1500)$	1468^{+14+23}_{-15-74}	$136^{+41+28}_{-26-100}$	$(1.65^{+0.26+0.51}_{-0.31-1.40}) \times 10^{-5}$	8.2σ
$f_0(1710)$	1759^{+6+14}_{-25}	172^{+10+32}_{-16}	$(2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$	25.0σ
$f_0(2100)$	2081^{+13+24}_{-36}	273^{+27+70}_{-24-23}	$(1.13^{+0.09+0.64}_{-0.10-0.28}) \times 10^{-4}$	13.9σ
$f'_2(1525)$	1513^{+5+4}_{-10}	75^{+12+16}_{-10-8}	$(3.42^{+0.43+1.37}_{-0.51-1.30}) \times 10^{-5}$	11.0σ
$f_2(1810)$	1822^{+29+66}_{-24-57}	$229^{+52+88}_{-42-155}$	$(5.40^{+0.60+3.42}_{-0.67-2.35}) \times 10^{-5}$	6.4σ
$f_2(2340)$	$2362^{+31+140}_{-30-63}$	$334^{+62+165}_{-54-100}$	$(5.60^{+0.62+2.37}_{-0.65-2.07}) \times 10^{-5}$	7.6σ

2.1.2. Study of the near-threshold $\omega\phi$ mass enhancement in doubly OZI suppressed $J/\psi \rightarrow \gamma\omega\phi$ decays

We use $(225.3 \pm 2.8) \times 10^6$ J/ψ events accumulated with the BESIII detector to study the doubly OZI suppressed decays of $J/\psi \rightarrow \gamma\omega\phi$, $\omega \rightarrow \pi^0\pi^+\pi^-$, $\phi \rightarrow K^+K^-$.²³ A strong deviation from three-body phase space for $J/\psi \rightarrow \gamma\omega\phi$ near the $\omega\phi$ invariant-mass threshold is observed. Assuming the enhancement is due to the influence of a resonance, the $X(1810)$, a partial wave analysis with a tensor covariant

Fig. 2. Comparisons between data and PWA fit projections on the $\phi\omega$ invariant-mass distribution.

amplitude shown in Fig. 2 determines that the spin-parity of the $X(1810)$ is 0^{++} , and the statistical significance of the $X(1810)$ is more than 30σ . The mass and width of the $X(1810)$ are determined to be $M = 1795 \pm 7(\text{stat})_{-5}^{+13}(\text{syst}) \pm 19(\text{mod}) \text{ MeV}/c^2$ and $\Gamma = 95 \pm 10(\text{stat})_{-34}^{+21}(\text{syst}) \pm 75(\text{mod}) \text{ MeV}/c^2$ and the product branching fraction is measured to be $B(J/\psi \rightarrow \gamma X(1810)) \times B(X(1810) \rightarrow \omega\phi) = (2.00 \pm 0.08(\text{stat})_{-1.00}^{+0.45}(\text{syst}) \pm 1.30(\text{mod})) \times 10^{-4}$, where the first error indicates the statistical error and the second is the systematical error. These results are consistent within errors with those from the BESII experiment.²⁴

2.2. Study of $J/\psi \rightarrow \eta\phi\pi^+\pi^-$ at BESIII

2.2.1. Study of $Y(2175)$

In the analysis, the ϕ and η meson are reconstructed with K^+K^- and $\gamma\gamma$ decay modes, respectively, and the events candidates of $J/\psi \rightarrow \phi\pi^+\pi^-\eta$ are required to have four well reconstructed charged tracks with net charge zero and at least two photons. After the above selection, the scatter plot of $M(K^+K^-)$ versus $M(\gamma\gamma)$ is shown in Fig. 3(a), where the box with solid line shows the η and ϕ signal region, and the boxes with dotted lines show the two-dimensional η and/or ϕ sidebands regions, which will be used to estimate the non- η and/or non- ϕ background contributions following. In the $\pi^+\pi^-$ mass spectrum (Fig. 3 (b)) distribution, around the $f_0(980)$ signal region, beside the $f_0(980)$ signal and the small contamination of non- η /non- ϕ background, the events from $J/\psi \rightarrow \phi\eta\pi^+\pi^-$ without the intermediate state $f_0(980)$ is found to be the dominant contribution. A method of three-dimensional weighted

Fig. 3. (a) A scatter plot of $M(K^+K^-)$ versus $M(\gamma\gamma)$, the boxes with solid line and with dotted line show the η and ϕ signal region and sidebands regions, respectively. (b) The $\pi^+\pi^-$ invariant mass spectrum. The shadow histograms shown the non- η /non- ϕ background estimated with sideband regions, the dotted and solid arrows denote $f_0(980)$ signal region and sideband regions, respectively. (c) The $\phi f_0(980)$ invariant mass distribution. The circle dots with error bars show the distribution for signal, the triangle dots with error bars for the backgrounds estimated by sidebands. The solid curve shows the overall fit projection, the dotted curve shows the fit for the backgrounds, and the dashed curve for the sum of the direct decay of $J/\psi \rightarrow \eta\phi f_0$ and backgrounds.

sideband of $\eta - \phi - f_0(980)$ is used to investigate if the $Y(2175)$ observed in $\phi\pi^+\pi^-$ invariant mass distribution is from non- η , non- ϕ or non- $f_0(980)$ backgrounds. The weighted factors are extracted from the a three-dimensional fit to the invariant mass distribution of $\gamma\gamma$ versus K^+K^- versus $\pi^+\pi^-$. The estimated $\phi\pi^+\pi^-$ invariant mass distribution of the total non- η , non- ϕ or non- $f_0(980)$ components is shown by the triangle dots with error bars in Fig. 3 (c), no evident of $Y(2175)$ signal is observed.

The fit results are shown in Fig. 3 (c), the corresponding mass and width of $Y(2175)$ are $M = 2199 \pm 6$ MeV/c² and $\Gamma = 106 \pm 15$ MeV/c², respectively. The fit yields 488 ± 54 event of $Y(2175)$ with a statistical significance of more than 8σ .

Besides, we also have a discussion on the predictions of the nature of $Y(2175)$, which are including $s\bar{s}$ -gluon hybrid,⁵ excited ϕ state,⁶ tetraquark state,⁷ as well as the $\Lambda\bar{\Lambda}$ bound state.^{8,9} By now, we could not exclude any one of these predictions and the nature of $Y(2175)$ is still confusing for us.

2.2.2. $J/\psi \rightarrow \phi f_1(1285), \phi\eta(1405)$

In addition, we performed the investigation of $\eta\pi^+\pi^-$ mass spectrum again ϕ signal in the J/ψ decay. A structure around 1.28 GeV/c² is clear seen, and the fit results are in good agreement with the world average value of $f_1(1285)$. The product branching fraction of $J/\psi \rightarrow \phi f_1(1285)$, $f_1(1285) \rightarrow \eta\pi^+\pi^-$ is measured to be $\mathcal{B}(J/\psi \rightarrow \phi f_1(1285), f_1(1285) \rightarrow \eta\pi^+\pi^-) = (1.15 \pm 0.06 \pm 0.14) \times 10^{-4}$. A bump around 1.4 GeV/c² is evident in the $\eta\pi^+\pi^-$ invariant mass spectrum. With an assumption of $\eta(1405)$, the product branching fraction is calculated to be $\mathcal{B}(J/\psi \rightarrow \phi\eta(1405), \eta(1405) \rightarrow \pi^+\pi^-\eta) = (2.01 \pm 0.58 \pm 0.80) \times 10^{-5}$. Meanwhile, we also present a 90% C.L. upper limit $\mathcal{B}(J/\psi \rightarrow \phi\eta(1405), \eta(1405) \rightarrow \pi^+\pi^-\eta) < 4.45 \times 10^{-5}$ since its statistical significance is just 3.6σ . In the previous experiment,

Fig. 4. Fitting results of $f_1(1285)$ and $\eta(1405)$. The dashed line denotes non- η and non- ϕ backgrounds estimated by η - ϕ sideband, the dotted curve represents $J/\psi \rightarrow \eta\phi\pi^+\pi^-$ component. The solid histogram indicates the shape of $X(1835)$, and the dash-dotted histogram indicates the signal of $X(1870)$.

Table 2. The measurements of the events number, statistical significance, efficiencies, and the branching fractions.

Resonance	N_{obs}	Significance	$\mathcal{B}$
$Y(2175)$	488 ± 54	$> 8\sigma$	$(1.24 \pm 0.14 \pm 0.31) \times 10^{-4}$
$f_1(1285)$	1154 ± 56	—	$(1.15 \pm 0.06 \pm 0.14) \times 10^{-4}$
$\eta(1405)$	$172 \pm 50 (< 345)$	3.6σ	$(2.01 \pm 0.58 \pm 0.80)(< 4.45) \times 10^{-5}$
$X(1835)$	< 1522	1.1σ	$< 2.80 \times 10^{-4}$
$X(1870)$	< 330	0.8σ	$< 6.13 \times 10^{-5}$

the $\eta(1405)/\eta(1440)$ is observed in both the $\eta\pi\pi$ and $K\bar{K}\pi$ invariant mass recoiling against γ and ω signal in J/ψ decay. However, no significant $\eta(1405)$ is observed in $\pi^+\pi^-\eta$ mass spectrum recoiling against ϕ in this analysis, which may imply u and d quarks account for more of quark content in $\eta(1405)$ than s quark. We also performed the searches for $X(1835)$ and $X(1870)$ in the vicinity of $1.8 \text{ GeV}/c^2$ in the $\eta\pi^+\pi^-$ mass spectrum, and no evident structures are observed. The corresponding upper limits at 90% C.L. of branching fraction are measurement, respectively. All of these measurements will help to understand the nature of $X(1835)$ and $X(1870)$ particles. The fit results are shown in Fig. 4 and Tab. 2.

3. Summary

In this talk, recent results on the partial wave analysis of $J/\psi \rightarrow \gamma\eta\eta$, $\gamma\omega\phi$ and the study on $Y(2175)$ and $\eta(1405)$ are presented. The draft of study of $J/\psi \rightarrow \eta\phi\pi^+\pi^-$ at BESIII has been releases to the collaboration. One billion J/ψ and 0.4 billion $\psi(2S)$ events are taken recently and more results are expected.

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References

1. L.C. Gui, Y. Chen *et al.*, Phys. Rev. Lett. **110**, 021601 (2013).
2. E. Gregory *et al.*, JHEP **1210**, 170 (2012).
3. B. Aubert *et al.* (BABAR Collaboration), Phys. Rev. D **74**, 091103(R) (2006).
4. J. Beringer *et al.* (Particle Data Group), Phys. Rev. D **86** (2012).
5. G. J. Ding and M. L. Yan, Phys. Lett. B **650**, 390 (2007).
6. G. J. Ding and M. L. Yan, Phys. Lett. B **657**, 49 (2007).
7. Z. G. Wang, Nucl. Phys. A **791**, 106 (2007).
8. E. Klempt and A. Zaitsev, Phys. Rept. **454**, 1 (2007).
9. C. F. Qiao, Phys. Lett. B **639**, 263 (2006).
10. B. Aubert *et al.* (BABAR Collaboration), Phys. Rev. D **86**, 012008 (2012).
11. C. P. Shen *et al.* (Belle Collaboration), Phys. Rev. D **80**, 031101(R) (2009).
12. M. Ablikim *et al.* (BES Collaboration), Phys. Rev. Lett. **100**, 102003 (2008).
13. N. R. Stanton *et al.*, Phys. Rev. Lett. **42**, 346 (1979).
14. J. J. Manak *et al.*, Phys. Rev. D **62**, 012003 (2000).
15. D. L. Scharre *et al.*, Phys. Lett. B **97**, 329 (1980).
16. H. J. Behrend *et al.* (CELLO Collaboration), Z. Phys.C **42**, 367 (1989).
17. I. Vodopianov *et al.* (L3 Collaboration), Acta Phys. Pol. B **31**, 2453 (2000).
18. D. Coffman *et al.* (MARKIII Collaboration), Phys. Rev. D **41**, 1410 (1990).
19. J. E. Augustin *et al.* (DM2 Collaboration), Phys. Rev. D **42**, 10 (1990).
20. C. Edwards, Ph.D. thesis, Cal.Tech. (Institution Report No CALT-68-1165 1985, (unpublished)).
21. M. Ablikim *et al.* (BES Collaboration), Phys. Lett. B **594**, 47 (2004).
22. M. Ablikim *et al.* (BESIII Collaboration), Phys. Rev. D **87**, 092009 (2013).
23. M. Ablikim *et al.* (BESIII Collaboration), Phys. Rev. D **87**, 032008 (2013).
24. M. Ablikim *et al.* (BES Collaboration), Phys. Rev. Lett. **96**, 162002 (2006).