PROCEEDINGS OF SCIENCE

Light Meson Spectroscopy at BESIII

Guoyi Hou (on behalf of the BESIII Collaboration)[a,*]

[a] *Institution of High Energy Physics, CAS,*
19B Yuquan Road, Shijingshan District, Beijing, China

E-mail: hougy@ihep.ac.cn

BESIII has the world's largest samples of J/ψ and $\psi(3686)$ events from e^+e^- annihilations, which offer an ideal laboratory to study light meson spectroscopy, in particular for the search of QCD exotics with gluonic excitations. The observation of a 1^{-+} state, $\eta_1(1855)$ in $J/\psi \to \gamma\eta\eta'$, the observation of the $X(2600)$ in $J/\psi \to \gamma\pi^+\pi^-\eta'$, and the observation of J/ψ Electromagnetic Dalitz Decays to $X(1835)$, $X(2120)$ and $X(2370)$ will be discussed in this proceeding.

41st International Conference on High Energy physics - ICHEP2022
6-13 July, 2022
Bologna, Italy

[*] Speaker

PoS(ICHEP2022)780

1. Introduction

Confinement is a unique property of QCD. The quark model describes mesons as bound states of quarks and antiquarks. The LQCD and QCD-motivated models for hadrons, however, predict a richer spectrum of mesons. One of the primary goals of BESIII experiment is to study those QCD exotics. Understanding these states will provide critical information for the quantitative understanding of confinement [1–5]. BESIII has collected 10 billion J/ψ events, which is the largest J/ψ data sample produced in e^+e^- annihilation in the world. The J/ψ decays are gluon-rich processes and therefore provide an ideal place to perform systematic studies of light meson spectroscopy, especially the QCD exotics with gluonic excitation.

2. Observation of an exotic isoscalar state $\eta_1(1855)$ in $J/\psi \to \gamma\eta\eta'$

Hybrid mesons are $q\bar{q}$ states with explicit excitations of the gluon field. Models and LQCD predict that the exotic $J^{PC} = 1^{-+}$ nonet of hybrid mesons is the lightest, with a mass around 1.7–2.1 GeV/c^2 [6–8]. There are currently three 1^{-+} candidates: the $\pi_1(1400)$, $\pi_1(1600)$, and $\pi_1(2015)$, which are all isovector states. Finding an isoscalar 1^{-+} hybrid state is critical for establishing the hybrid multiplet [4, 5]. Decaying to $\eta\eta'$ in a P wave is expected for an isoscalar 1^{-+} hybrid state [9–11].

A Partial Wave Analysis (PWA) of $J/\psi \to \gamma\eta\eta'$ has been performed based on $(10.09 \pm 0.04) \times 10^9 J/\psi$ events collected with the BESIII detector [12, 13]. An isoscalar state $\eta_1(1855)$ with exotic quantum numbers $J^{PC} = 1^{-+}$ has been observed for the first time. Fig. 1(a) shows the invariant mass distribution of $\eta\eta'$ and Fig. 1(b) shows the distribution of the unnormalized moment in which the need for the $\eta_1(1855)$ component is apparent. Its mass and width are measured to be $(1855 \pm 9^{+6}_{-1})$ MeV/c^2 and $(188 \pm 18^{+3}_{-8})$ MeV, which are consistent with LQCD calculations for the 1^{-+} hybrid [7]. The first uncertainties are statistical and the second are systematic. The statistical significance of the resonance hypothesis is estimated to be larger than 19σ. The product branching fraction $\mathcal{B}[J/\psi \to \gamma\eta_1(1855)]\mathcal{B}[\eta_1(1855) \to \eta\eta']$ is measured to be $(2.70 \pm 0.41^{+0.16}_{-0.35})$. The $\eta_1(1855)$ has stimulated many theoretical interpretations, such as an isoscalar light hybrid [14–16], a $K\bar{K}_1(1400)$ molecular state [17], or a tetraquark state [18]. Further studies with more production mechanisms and decay modes will help clarify the nature of the $\eta_1(1855)$.

In addition, the decay $\to \gamma f_0(1500) \to \gamma\eta$ has also been observed (>30σ), while $\to \gamma f_0(1710) \to \gamma\eta$ is found to be insignificant. The ratio $(f_0(1500) \to \eta)/(f_0(1500) \to \pi\pi)$ is measured to be $(8.96^{+2.95}_{-2.87})\times10^{-2}$, which is consistent with the PDG value [19]. For the first time, the upper limit on the ratio of $(f_0(1710) \to \eta)/(f_0(1710) \to \pi\pi)$ at 90% confidence level is determined to be 1.61×10^{-3}. The suppressed decay rate of the $f_0(1710)$ into η lends further support to the hypothesis that the $f_0(1710)$ has a large overlap with the ground state scalar glueball [20].

3. A new state $X(2600)$ observed in $J/\psi \to \gamma\pi^+\pi^-\eta'$

In the process $J/\psi \to \gamma\pi^+\pi^-\eta'$, the $X(1835)$ was first observed [21] and confirmed [22]. The $X(2120)$ and the $X(2370)$ was also observed in this channel [22]. Using the 10 billion J/ψ data, a new resonance $X(2600)$ is observed [23], with a statistical significance greater than 20 σ, as

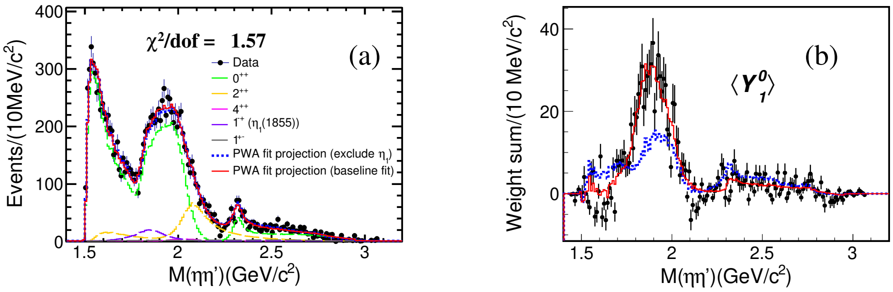

Figure 1: (a) Fit to the $\eta\eta'$ invariant mass distribution and (b) the distribution of the unnormalized moment $\langle Y_1^0 \rangle$ for $J/\psi \to \gamma\eta\eta'$ as functions of the $\eta\eta'$ mass. Black dots with error bars represent the background-subtracted data weighted with angular moments; the red solid lines represent the baseline fit projections; and the blue dotted lines represent the projections from a fit excluding the η_1 component.

shown in Fig. 2. There is a strong correlation between the $X(2600)$ and the structure at 1.5 GeV/c^2 in the $\pi^+\pi^-$ invariant mass spectrum. A simultaneous fit of the $\pi^+\pi^-\eta'$ and $\pi^+\pi^-$ mass spectra with the two η' decay channels of $\eta' \to \gamma\pi^+\pi^-$ and $\eta' \to \pi^+\pi^-\eta$ is performed. The structure around 1.5 GeV/c^2 in the $\pi^+\pi^-$ invariant mass spectra can be well described with the interference between the $f_0(1500)$ and the $X(1540)$ resonances. The masses and width of the $X(2600)$ are measured to be $2618.3 \pm 2.0(\text{stat.})^{+16.3}_{-1.4}(\text{sys.})$ MeV/c^2 and $195 \pm 5(\text{stat.})^{+26}_{-17}(\text{sys.})$ MeV. The corresponding product branching fractions are measured to be $B(J/\psi \to \gamma X(2600)) \cdot B(X(2600) \to f_0(1500)\eta') \cdot B(f_0(1500) \to \pi^+\pi^-) = 3.09 \pm 0.21^{+1.14}_{-0.77}$ and $B(J/\psi \to \gamma X(2600)) \cdot B(X(2600) \to X(1540)\eta') \cdot B(X(1540) \to \pi^+\pi^-) = 2.69 \pm 0.19^{+0.38}_{-1.21}$.

Based upon the observed decay modes, the nature of $X(1540)$ is not known and can be further investigated via the decay channel of $J/\psi \to \gamma K^+K^-\eta'$. In order to understand the nature of the $X(2600)$ state, whether it can be interpreted as an η radial excitation or an exotic hadron, it is important to determine its spin parity and to study its production and decay properties in other J/ψ decay channels.

4. Observation of J/ψ EM Dalitz Decays to $X(1835)$, $X(2120)$ and $X(2370)$

The electromagnetic Dalitz decays $J/\psi \to e^+e^-\pi^+\pi^-\eta'$, with $\eta' \to \gamma\pi^+\pi^-$ and $\eta' \to \pi^+\pi^-\eta$, have been studied [24]. The $X(1835)$, $X(2120)$ and $X(2370)$ are observed for the first time in the J/ψ EM Dalitz decays, as shown in Fig. 3. According to the model of a coherent sum of two Breit-Wigner amplitudes of $X(1835)$ and $X(1870)$, the branching fraction of $J/\psi \to e^+e^-X(1835)$, $X(1835) \to \pi^+\pi^-\eta'$ is measured to be $(3.58 \pm 0.19(\text{stat}) \pm 0.16(\text{syst})) \times 10^{-6}$ (constructive interference)/ $(4.43 \pm 0.23(\text{stat}) \pm 0.19(\text{syst})) \times 10^{-6}$ (destructive interference) with a significance of 15σ. With respect to the radiative decay $J/\psi \to \gamma X(1835)$, $X(1835) \to \pi^+\pi^-\eta'$ [25], the ratio R of the branching fractions is determined to be $(1.19 \pm 0.10(\text{stat}) \pm 0.14(\text{syst})) \times 10^{-2}$. The measured R is consistent with the theoretical prediction [26] within two standard deviations (2σ). The branching fractions of $J/\psi \to e^+e^-X(2120)$, $X(2120) \to \pi^+\pi^-\eta'$ and $J/\psi \to e^+e^-X(2370)$, $X(2370) \to \pi^+\pi^-\eta'$ are measured to be $(0.82 \pm 0.12(\text{stat}) \pm 0.06(\text{syst})) \times 10^{-6}$ and $(1.08 \pm 0.14(\text{stat}) \pm 0.10(\text{syst})) \times 10^{-6}$ with significance of 5.3σ and 7.3σ, respectively.

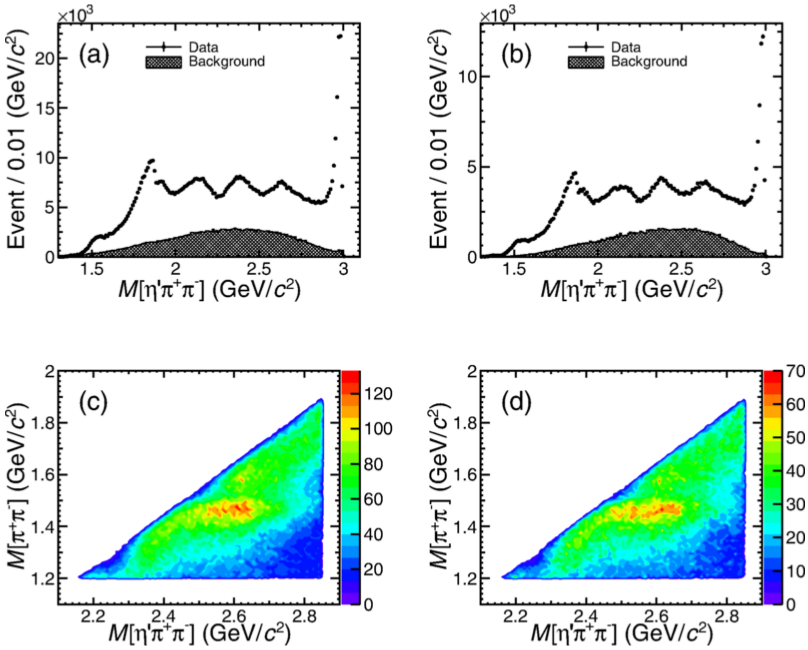

Figure 2: (top) The invariant mass spectrum of the final state $\pi^+\pi^-\eta'$ after event selection with (a) the $\eta' \to \gamma\pi^+\pi^-$ channel and (b) the $\eta' \to \pi^+\pi^-\eta$ channel. (bottom) The two dimensional distribution of $M_{\pi^+\pi^-}$ versus $M_{\pi^+\pi^-\eta'}$ with $M_{\pi^+\pi^-} > 1.2$ GeV/c^2 and $2.2 < M_{\pi^+\pi^-\eta'} < 2.85$ GeV/c^2 with (c) the $\eta' \to \gamma\pi^+\pi^-$ channel and (d) the $\eta' \to \pi^+\pi^-\eta$ channel.

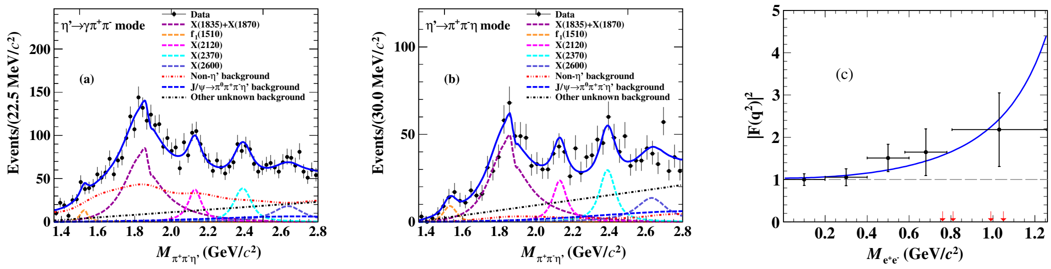

Figure 3: Invariant mass distributions of $M_{\pi^+\pi^-\eta'}$ for selected candidates, for the (a) $\eta' \to \gamma\pi^+\pi^-$ decay mode and (b) $\eta' \to \pi^+\pi^-\eta$ decay mode. And (c) $|F(q^2)|^2$ distribution for $J/\psi \to e^+e^-X(1835)$ decays.

Besides, the EM transition form factors (TFF) of $J/\psi \to e^+e^-X(1835)$ is measured for the first time, as shown in Fig. 3(c). The measured values of $|F(q^2)|^2$ deviate from the point-like particle assumption ($|F(q^2)|^2 = 1$) significantly and have been parameterized in the simple pole approximation as $F(q^2) = \frac{1}{1-q^2/\Lambda^2}$ with $\Lambda = (1.75 \pm 0.29(\text{stat}) \pm 0.05(\text{syst}))$ GeV/c^2, which give additional information of the internal structure of the X(1835).

5. Summary

As shown in this report, J/ψ decays provide an excellent laboratory to study light meson physics. In particular, the 10 billion of J/ψ data collected by BESIII will allow the study of light meson decays with unprecedented statistics, and many new results are expected in the near future.

References

[1] N. Brambilla *et al.*, Eur. Phys. J. C **74**, 2981 (2014).

[2] C. Amsler and N. A. Tornqvist, Phys. Rept. **389**, 61 (2004).

[3] S. Godfrey and J. Napolitano, Rev. Mod. Phys. **71**, 1411 (1999).

[4] C. A. Meyer and Y. Van Haarlem, Phys. Rev. C **82**, 025208 (2010).

[5] E. Klempt and A. Zaitsev, Phys. Rept. **454**, 1 (2007).

[6] P. Lacock, C. Michael, P. Boyle, and P. Rowland (UKQCD), Phys. Lett. B **401**, 308 (1997).

[7] J. J. Dudek, R. G. Edwards, P. Guo, and C. E. Thomas (Hadron Spectrum), Phys. Rev. D **88**, 094505 (2013).

[8] C. A. Meyer and E. S. Swanson, Prog. Part. Nucl. Phys. **82**, 21 (2015).

[9] H.-X. Chen, Z.-X. Cai, P.-Z. Huang, and S.-L. Zhu, Phys. Rev. D **83**, 014006 (2011).

[10] P.-Z. Huang, H.-X. Chen, and S.-L. Zhu, Phys. Rev. D **83**, 014021 (2011).

[11] W. I. Eshraim, C. S. Fischer, F. Giacosa, and D. Parganlija, Eur. Phys. J. Plus **135**, 945 (2020).

[12] M. Ablikim *et al.* (BESIII), Phys. Rev. Lett. **129**, 192002 (2022).

[13] M. Ablikim *et al.* (BESIII), Phys. Rev. D **106**, 072012 (2022).

[14] H.-X. Chen, N. Su, and S.-L. Zhu, Chin. Phys. Lett. **39**, 051201 (2022).

[15] L. Qiu and Q. Zhao, Chin. Phys. C **46**, 051001 (2022).

[16] V. Shastry, C. S. Fischer, and F. Giacosa, Phys. Lett. B **834**, 137478 (2022).

[17] X.-Y. Wang, F.-C. Zeng, and X. Liu, Phys. Rev. D **106**, 036005 (2022).

[18] B.-D. Wan, S.-Q. Zhang, and C.-F. Qiao, Phys. Rev. D **106**, 074003 (2022).

[19] P. A. Zyla *et al.* (Particle Data Group), PTEP **8**, 083C01 (2020).

[20] F. Brünner and A. Rebhan, Phys. Rev. D **92**, 121902 (2015).

[21] M. Ablikim *et al.* (BES), Phys. Rev. Lett. **95**, 262001 (2005).

[22] M. Ablikim *et al.* (BESIII), Phys. Rev. Lett. **106**, 072002 (2011).

[23] M. Ablikim *et al.* (BESIII), Phys. Rev. Lett. **129**, 042001 (2022).

[24] M. Ablikim *et al.* (BESIII), Phys. Rev. Lett. **129**, 022002 (2022).

[25] M. Ablikim *et al.* (BESIII), Phys. Rev. Lett. **117**, 042002 (2016).

[26] J. Zhang, J. He, T. Zhu, S. Xu, and R. Wang, Int. J. Mod. Phys. A **34**, 1950129 (2019).