PROCEEDINGS OF SCIENCE

Light hadron spectroscopy at BESIII

Runqiu Ma[a,*]

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

E-mail: marq@ihep.ac.cn

The BESIII detector has collected the largest $J/\psi, \psi'$ data samples since the upgrade was completed in 2008. The light hadron spectroscopy, as one of the main physics goals, was extensively studied and many important progresses were achieved these years. In this report the recent results on the study of hadron spectroscopy were presented.

40th International Conference on High Energy physics - ICHEP2020
July 28 - August 6, 2020
Prague, Czech Republic (virtual meeting)

---

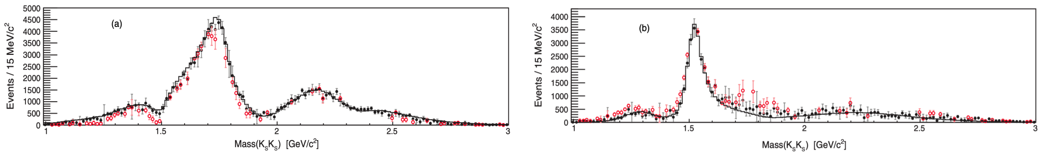
[*] Speaker

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 that takes into accounts not only the quark degrees of freedom but also the gluonic degrees of freedom. The primary goal of BESIII experiment is to search for and study those QCD exotics or states with composition that is different from normal mesons and baryons. Understanding these states will provide critical information for the quantitative understanding of confinement. Data with unprecedented statistical accuracy and clearly defined initial and final state properties resulted in significant advances in recent years, and offer great opportunities to investigate hadron spectroscopy at BESIII.

2. Study of scalar and tensor glueballs

An amplitude analysis of the K_sK_s system produced in radiative J/ψ decays is performed using the 1310.6×10^6 J/ψ decays collected by the BESIII detector with mass-dependent and mass-independent method [1]. A mass-dependent amplitude analysis is used to study the existence and coupling of various intermediate states including light isoscalar resonances. The dominant scalar amplitudes come from the $f_0(1710)$ and $f_0(2200)$ which is shown in Fig.1(*a*). The production rate of the $f_0(1710)$ is about 1 order of magnitude larger than that of the $f_0(1500)$, Similar feature of branching fractions is also observed in the amplitude analysis of $J/\psi \to \gamma\eta\eta$ [2]. With the new measurements from BESIII, the $f_0(1710)$ has been founded in J/ψ radiative decay of $K_sK_s, \eta\eta$ [2] ,$\pi\pi$ [3] spectra. And the known branching fraction of $f_0(1710)$ is already comparable with the LQCD calculations of a scalar glueball [4], which suggests that the $f_0(1710)$ has a larger overlap with the glueball compared to the $f_0(1500)$. The tensor contribution above 2 GeV is dominantly $f_2(2340)$ which is shown in Fig.1(*b*). Recent LQCD predictions for the production rate of the tensor glueball in radiative J/ψ decays [5] are inconsistent with the production rate of the $f_2(2340)$ in the $K_sK_s, \eta\eta$ [2] ,$\phi\phi$ [6] spectra. The mass-dependent results are consistent with the result of a mass-independent amplitude analysis of K_sK_s invariant mass spectrum.



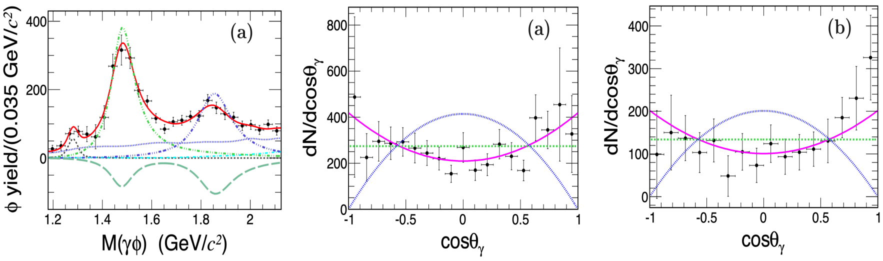
(a) (b)

Figure 1: Intensities for the total (a)0^{++} and (b)2^{++} amplitudes as a function of K_sK_s invariant mass for the nominal results without acceptance correction. The solid black markers show one set of solutions from the mass-independent analysis, while the open red markers represent its ambiguous partner and the histogram shows the results of the mass-dependent analysis.

3. Study of pseudoscalar meson spectroscopy

The state X(1835) was first observed by the BES experiment as a peak in $J/\psi \to \gamma\eta'\pi^+\pi^-$ decays [7]. This observation was later confirmed by BESIII [8]. The X(1835) was also observed in the $\eta K_s^0 K_s^0$ channel, where its spin-parity was determined to be $J^P = 0^-$ by PWA [9]. An anomalously strong enhancement at the proton-antiproton($p\overline{p}$) mass threshold, dubbed $X(p\overline{p})$, was first observed by BES in $J/\psi \to \gamma p\overline{p}$ decays [10]. This observation was confirmed by BESIII and CLEO. This enhancement was subsequently determined to have the spin-parity $J^P = 0^-$ by BESIII [11]. Recent BESIII study [12] indicates that X(1835) is a $p\overline{p}$ molecule-like state or a bound state.

Based on a sample of 1.31 billion J/ψ events taken with the BESIII detector, we have studied the decay $J/\psi \to \gamma\gamma\phi$ [13]. Two structures around 1475 MeV/c^2 and 1835 MeV/c^2 are observed in the $\gamma\phi$ invariant mass spectrum as shown in Fig.2(*a*). And the resonance parameters are determined to be M(1475) = 1477±7 ± 13 MeV/c^2, Γ(1475) = 118 MeV/c^2 with a statistical significance 13.5σ and M(1835) = 1839±26±26 MeV/c^2, Γ(1835) = 175±57±25 MeV/c^2 with a statistical significance 6.3σ. A fit on the polar angle distribution of the radiative photon favor $J^{PC} = 0^{-+}$ assignment for the two resonances as shown in Fig.2(*b*),2(*c*). The obtained information supports the two new observed resonances are η(1475) and X(1835). The flavor filter reaction X(pseudoscalars) $\to \gamma V(\phi, \omega, \rho)$ indicates that both η(1475) and X(1835) contain a sizeable $s\overline{s}$ component.



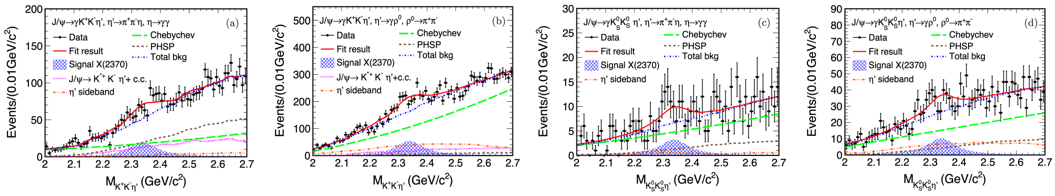
(a) (b) (c)

Figure 2: (a)Fits of $M_{\gamma\phi}$ (b) Fits to the efficiency-corrected cosθ_γ distributions for 1.4<M(γK^+K^-)<1.6 GeV/c^2 (c) Fits to the efficiency-corrected cosθ_γ distributions for 1.75<M(γK^+K^-)<1.9 GeV/c^2

In addition, based on same data set, we trying to search X(1835) in the hadronic process $J/\psi \to \omega\eta'\pi^+\pi^-$ [14]. No significant signal is observed and the upper limit at 90% C.L. on the branching fraction is determined to be Br($J/\psi \to \omega X(1835), X(1835) \to \eta'\pi^+\pi^-$) < 6.2×10^{-5}.

Except X(1835), two additional structure , the X(2120) and the X(2370), were also observed in $J/\psi \to \gamma\eta'\pi^+\pi^-$ [8] [12]. The measured mass of the X(2370) is consistent with the pseudoscalar glueball candidate predicted by LQCD calculation[15]. Assuming a pseudoscalar glueball at 2.37 GeV/c^2 decays to $\eta'\pi\pi$, a sizeable decay width to $\eta' KK$ is predicted [16].

Based on a sample of 1.31 billion J/ψ events collected with the BESIII detector, the decays of $J/\psi \to \gamma K^+K^-\eta'$ and $J/\psi \to \gamma K_s^0 K_s^0 \eta'$ are investigated using the two η' decay modes, $\eta' \to \gamma\pi^+\pi^-$ and $\eta' \to \eta\pi^+\pi^-$ [17] as shown in Fig.3. The X(2370) is observed in $K\overline{K}\eta'$ invariant mass distribution with a statistical significance of 8.3σ. The mass, width and branching fraction are determined to be : $M_{X(2370)} = 2341.6\pm6.5\pm5.7$ MeV/c^2, $\Gamma_{X(2370)} = 117\pm10\pm8$ MeV/c^2, Br($J/\psi \to \gamma X(2370) \to \gamma K^+K^-\eta'$) = $(1.79\pm0.23 \pm 0.65)\times 10^{-5}$ and Br($J/\psi \to \gamma X(2370) \to \gamma K_s^0 K_s^0 \eta'$) = $(1.18\pm0.32 \pm 0.39)\times 10^{-5}$. The mass and width are well consistent with X(2370) observed in $J/\psi \to \gamma\eta'\pi^+\pi^-$ [8] [12]. No evident signal for the X(2120) is observed in the $K\overline{K}\eta'$ invariant mass distribution. Upper limits for product branching fractions at 90% C.L. are determined to be Br($J/\psi \to \gamma X(2120) \to \gamma K^+K^-\eta'$) < 1.49×10^{-5} and r($J/\psi \to \gamma X(2120) \to \gamma K_s^0 K_s^0 \eta'$) < 6.38 $\times10^{-6}$. However, the spin-parity of these two new structures have not yet been determined. In the future, amplitude analysis is needed to identify the J^{PC}, and it is crucial to explore other decay modes.

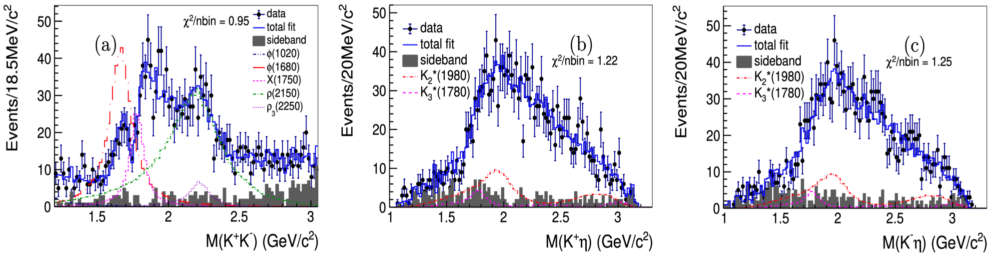


(a) (b) (c) (d)

Figure 3: The fit result for X(2370) in the invariant mass distribution of $K\overline{K}\eta'$.

4. Strange quarkonium

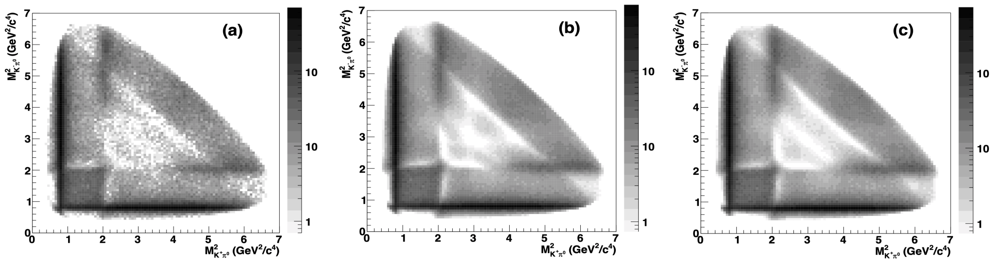
Using a sample of 4.48×10^8 $\psi(3686)$ events collected with the BESIII detector, we perform a partial wave analysis of $\psi(3686) \to K^+K^-\eta$ as shown in Fig.4. In addition to the well established states, $\phi(1020)$, $\phi(1680)$, and $K_3^*(1780)$, contribution from X(1750), $\rho(2150)/\phi(2170)$, $\rho_3(2250)$, and $K_2^*(1980)$ are also observed. The X(1750) state is determined to be a 1^{--} resonance, and the fitted mass and width are consistent with the result reported by the FOCUS Collaboration [19]. The simultaneous observation of the $\phi(1680)$ and X(1750) indicates that the X(1750), with previous observations in photoproduction, is distinct from the $\phi(1680)$. The isospin is undetermined , that is we can not distinguish state around 2150 MeV/c^2 from $\phi(2170)$ and $\rho(2150)$. Combined analysis with other channels is needed to distinguish these states as strangeonium or excited ρ states.



(a) (b) (c)

Figure 4: Comparisons to the fit projections for the (a) K^+K^- , (b)$K^+\eta$ and (c)$K^-\eta$ invariant mass distributions

A partial wave analysis of the decay $J/\psi \to K^+K^-\pi^0$ has been made using 223.7×10^{6} J/ψ events collected with the BESIII detector as shown in Fig.5. Two PWA solution are presented. In both cases, there is a set of reliably identified contributions. $K_2^*(1980)^{\pm}$ and $K_4^*(2045)^{\pm}$ are observed for the first time in J/ψ decays where the measured mass of $K_2^*(1980)^{\pm}$ is agrees with the expectation from the linear Regge trajectory of radial excitations with the standard slope [21]. $K^*(892)^{\pm}$ and $K_2^*(1430)^{\pm}$ are measured with improved precision compared to previous measurements. wo J^{PC} = 1^{--} states are observed. The first states with a mass of 1.65 GeV/c^2 may be interpreted as the ground $^3D_1$ isovector state. It's mass, width and small contribution to the decay are consistent with $\omega(1650)$ The second state with mass 2.05 GeV/c^2 can be interpreted as the $\rho(2150)$ or as another isovector-vector state that has been observed in proton-antiproton annihilation in flight[22]. The precise identification of these two states requires further analysis of more channel. We also report the most precise measurement of the branching fraction $\mathrm{Br}(J/\psi \to K^+K^-\pi^0) = (2.88 \pm 0.01 \pm 0.12) \times 10^{-3}$. The results of the partial wave analysis differ significantly from those previously obtained by BESII[23] and BaBar [24].



(a) (b) (c)

Figure 5: Dalitz plots for the selected data(a), the PWA solution I (b), and the PWA solution II (c).

5. Summary

Based on the data samples taken at the peak of $J/\psi, \psi(3686)$, the recent progresses on the hadron spectroscopy are reported in this talk. For the study of glueball candidates, the branching fraction of $f_0(1710)$ is one order of magnitude higher than that of $f_0(1500)$, which indicates $f_0(1710)$ has more gluonic component than $f_0(1500)$; The X(2370) is observed in $J/\psi \to \gamma KK\eta'$, while X(2120) is not observed. For the study of strangeonium, sign of X(1750) and $\phi(2170)$ has been observed in $\psi' \to K^+K^-\eta$; Two 1^{--} around 1650 MeV/c^2 and 2050 MeVc^2 has been observed in $J/\psi \to K^+K^-\pi^0$. BESIII collected 10 billions of J/ψ in 2019 and will continue to run for about 10 more years. Data with unprecedented statistical accuracy provides great opportunities to map out light meson spectroscopy and study QCD exotics.

References

[1] M. Ablikim *et al.* [BESIII], Phys. Rev. D **98** (2018) no.7, 072003

[2] M. Ablikim *et al.* [BESIII], Phys. Rev. D **87**, no.9, 092009 (2013)

[3] M. Ablikim *et al.* [BESIII], Phys. Rev. D **92**, no.5, 052003 (2015)

[4] L. C. Gui *et al.* [CLQCD], Phys. Rev. Lett. **110**, no.2, 021601 (2013)

[5] Y. B. Yang *et al.* [CLQCD], Phys. Rev. Lett. **111**, no.9, 091601 (2013)

[6] M. Ablikim *et al.* [BESIII], Phys. Rev. D **93**, no.11, 112011 (2016)

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

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

[9] M. Ablikim *et al.* [BESIII], Phys. Rev. Lett. **115**, no.9, 091803 (2015)

[10] J. Z. Bai *et al.* [BES], Phys. Rev. Lett. **91**, 022001 (2003)

[11] M. Ablikim *et al.* [BESIII], Phys. Rev. Lett. **108**, 112003 (2012)

[12] M. Ablikim *et al.* [BESIII], Phys. Rev. Lett. **117**, no.4, 042002 (2016)

[13] M. Ablikim *et al.* [BESIII], Phys. Rev. D **97**, no.5, 051101 (2018)

[14] M. Ablikim *et al.* [BESIII], Phys. Rev. D **99**, no.7, 071101 (2019)

[15] Y. Chen, A. Alexandru, S. J. Dong, T. Draper, I. Horvath, F. X. Lee, K. F. Liu, N. Mathur, C. Morningstar and M. Peardon, *et al.* Phys. Rev. D **73**, 014516 (2006)

[16] W. I. Eshraim, S. Janowski, F. Giacosa and D. H. Rischke, Phys. Rev. D **87**, no.5, 054036 (2013)

[17] M. Ablikim *et al.* [BESIII], Eur. Phys. J. C **80**, no.8, 746 (2020)

[18] M. Ablikim *et al.* [BESIII], Phys. Rev. D **101**, no.3, 032008 (2020)

[19] J. M. Link *et al.* [FOCUS], Phys. Lett. B **545**, 50-56 (2002)

[20] M. Ablikim *et al.* [BESIII], Phys. Rev. D **100**, no.3, 032004 (2019)

[21] V. V.Anisovich, AIP Conf.Proc. 619.197(2002)

[22] A. V. Anisovich, C. A. Baker, C. J. Batty, D. V. Bugg, C. Hodd, H. C. Lu, V. A. Nikonov, A. V. Sarantsev, V. V. Sarantsev and B. S. Zou, Phys. Lett. B **491**, 47-58 (2000)

[23] M. Ablikim *et al.* [BES], Phys. Rev. Lett. **97**, 142002 (2006)

[24] J. P. Lees *et al.* [BaBar], Phys. Rev. D **95**, no.7, 072007 (2017)