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Study of $\phi(2170)$ at BESIII

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The studies on the strangeonium state $\phi(2170)$ at BESIII are presented. The cross sections of the processes $e^+e^- \to K^+K^-$, $e^+e^- \to K^+K^-\pi^0\pi^0$, $e^+e^- \to K^+K^-K^+K^-/\phi K^+K^-$ and $e^+e^- \to \phi\eta'$ have been measured precisely in the center-of-mass energy region of 2.0 – 3.08 GeV, and the parameters of $\phi(2170)$ have been extracted from the lineshapes where applicable.

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1. Introduction

Charmonium ($c\bar{c}$) and bottomonium ($b\bar{b}$) states have been sufficiently studied in the past decades, and provide rigorous tests of QCD. It is natural to ask the question whether their strange companions, the strangeonium ($s\bar{s}$) states, behave in a similar way [1]. So far the spectrum of strangeonium has not been established well, both in theory predictions and in experimental observations. Below 2.2 GeV, there should be 22 $s\bar{s}$ resonances expected, but unfortunately only about half of them are identified. One reason might be, due to the smaller mass of the s quark, the strangeonium states are over crowded in the low energy region, and mixed with hybrids, glueballs and other exotics. With energy scan data in 2.0 – 3.08 GeV, BESIII has the potential to perform a direct search for strangeonium states in between, where an ideal target is the $\phi(2170)$.

The $\phi(2170)$, previously referred to as the Y(2175) [2], has been observed experimentally by *BABAR* [3, 4], Belle [5], BES [6] and BESIII [7, 8]. However the information is diverse, and even the measured mass and width of $\phi(2170)$ are controversial. There have also been different models for $\phi(2170)$, such as traditional $3\,^3S_1$ [9] or $2\,^3D_1$ $s\bar{s}$ [10] state, 1^{--} $s\bar{s}g$ hybrid [11, 12], tetraquark state [13–17], $\Lambda\bar{\Lambda}(^3S_1)$ bound state [18–21], S-wave threshold effect [22], or $\phi K\bar{K}$ resonance state [23]. The situation cannot be clarified without further experimental data.

2. Apparatus and data

The BESIII detector [24] is a magnetic spectrometer located at the Beijing Electron-Positron Collider (BEPCII) designed running at $\sqrt{s}$ from 2.0 to 4.6 GeV (upgraded to 4.9 GeV recently), which is a transition region between perturbative and non-perturbative QCD. The cylindrical-shaped detector has a geometrical acceptance of 93% of the full solid angle and has four main components: a small-cell, helium-based (60% He, 40% C_3H_8) main drift chamber (MDC), a time-of-fight system (TOF) based on 5-cm-thick plastic scintillators, an electromagnetic CsI(Tl) calorimeter (EMC) and the muon counter (MUC) based on Resistive Plate Chambers. BEPCII/BESIII is the only facility currently operating in the τ-charm region.

BESIII has been in operation since 2009, and more than 30 fb^{-1} integrated luminosity data has been accumulated. The e^+e^- collision data for QCD study include an integrated luminosity of 12 pb^{-1} at 4 energies in the continuum taken in 2012, about 800 pb^{-1} at 104 energies between 3.85 and 4.6 GeV taken in the 2013-2014 run, and about 650 pb^{-1} at 22 energies from 2.0 to 3.08 GeV taken in 2015. These are the so called scan data, with moderate luminosity at each energy point, nonetheless they are the largest data samples in the energy range in the world. There are much larger samples for charm physics or XYZ particle search, up to a few fb^{-1}'s at a single energy. The studies of $\phi(2170)$ covered in this write-up are based on the data in the continuum region between 2.0 and 3.08 GeV.

3. $e^+e^- \to K^+K^-$

BESIII measured the cross section lineshape of $e^+e^- \to K^+K^-$, where a resonance with mass $M = 2239.2 \pm 7.1 \pm 11.3$ MeV$/c^2$ and width $\Gamma = 139.8 \pm 12.3 \pm 20.6$ MeV was observed, as shown in Fig. 1 [25]. The process features mono-momentum final state tracks, based on which the signal can be easily separated from background without applying traditional particle identification method.

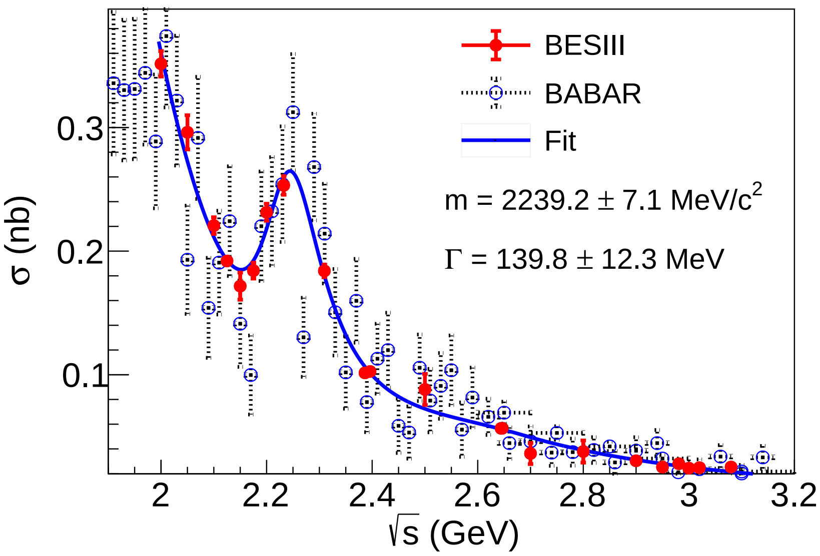

Figure 1: Born cross section of the $e^+e^- \to K^+K^-$ process.

4. $e^+e^- \to K^+K^-\pi^0\pi^0$

The process $e^+e^- \to K^+K^-\pi^0\pi^0$ was studied, and various sub-processes were carefully examined [26]. In Fig. 2, the lineshape of the sub-mode $e^+e^- \to \phi\pi^0\pi^0$ shows a likely resonance around 2.1 GeV. A further partial wave analysis including possible intermediate states reveals a structure with mass $M = 2126.5 \pm 16.8 \pm 12.4$ MeV$/c^2$ and width $\Gamma = 106.9 \pm 32.1 \pm 28.1$ MeV as shown in Fig. 3, which is not consistent with any of the existing theoretical models.

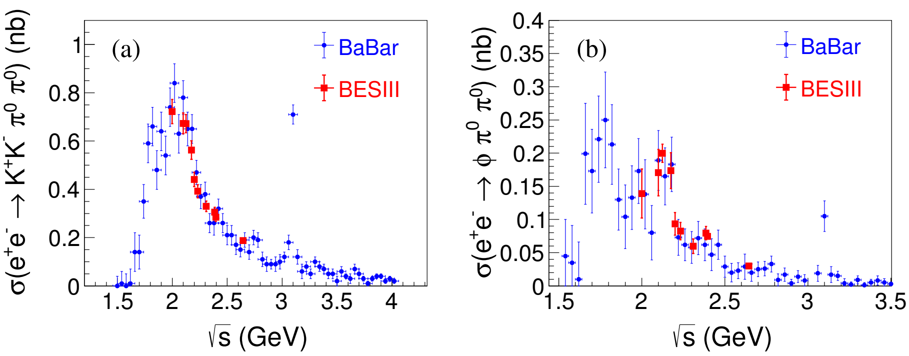

Figure 2: The Born cross sections for (a) $e^+e^- \to K^+K^-\pi^0\pi^0$, (b) $e^+e^- \to \phi\pi^0\pi^0$.

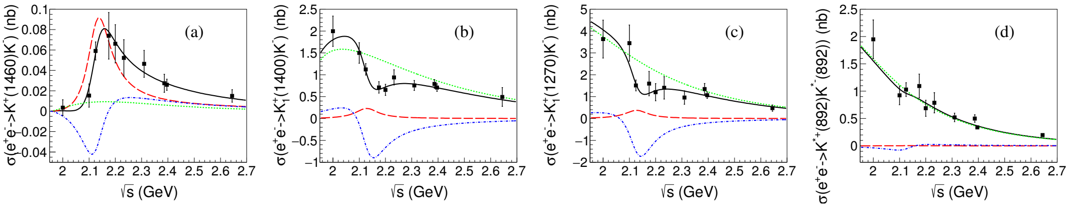

Figure 3: Fit to the cross sections for e^+e^- to the processes (a) $K^+(1460)K^-$, (b) $K_1^+(1400)K^-$, (c) $K_1^+(1270)K^-$ and (d) $K^{*+}(892)K^{*-}(892)$.

5. $e^+e^- \to K^+K^-K^+K^-/\phi K^+K^-$

Another channel $e^+e^- \to K^+K^-K^+K^-$, and also its dominant sub-mode $e^+e^- \to \phi K^+K^-$, are also measured [27] with the lineshapes illustrated in Fig. 4. In both cases, an enhancement at $\sqrt{s}$ = 2.232 GeV is observed, very close to the $e^+e^- \to \Lambda\bar{\Lambda}$ production threshold. The data is not sufficient to determine if there is a resonance, for which a finer scan would be needed.

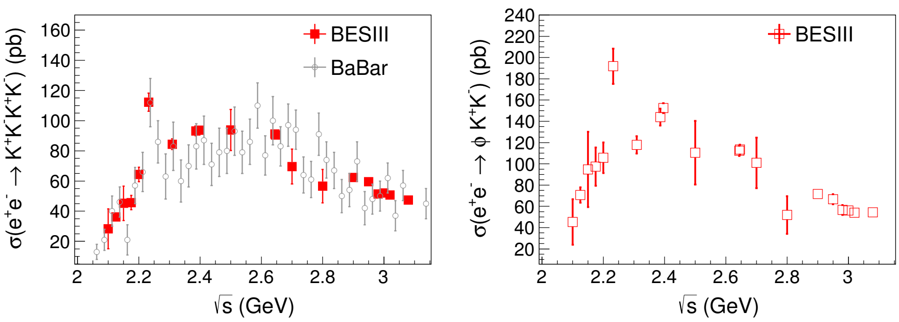

Figure 4: The measured Born cross section of $e^+e^- \to K^+K^-K^+K^-$ (left), $e^+e^- \to \phi K^+K^-$ (right).

6. $e^+e^- \to \phi\eta'$

The cross section of $e^+e^- \to \phi\eta'$ has been measured for the first time by BESIII in the energy range from 2.05 to 3.08 GeV [28]. The lineshape in Fig. 5 shows a prominent resonance with mass $M = (2177.5 \pm 4.8(\text{stat}) \pm 19.5(\text{syst}))$ MeV/c^2 and width $\Gamma = (149.0 \pm 15.6$ (stat) $\pm$ 8.9 (syst)) MeV. The observed structure is compatible with the $\phi(2170)$, and thus the ratio of partial width between the $\phi\eta'$ by BESIII and $\phi\eta$ by *BABAR* is $(\mathcal{B}^R_{\phi\eta}\Gamma^R_{ee})/(\mathcal{B}^R_{\phi\eta'}\Gamma^R_{ee}) = 0.23 \pm 0.10$ (stat) $\pm$ 0.18 (syst), which is smaller than the prediction of the $s\bar{s}g$ hybrid models by a few orders of magnitude [11, 12].

7. Summary

BESIII has made improved or new measurements of a nmuber of processes. These experimental results provide additional information in understanding the $\phi(2170)$. More studies, such as $e^+e^- \to \phi\pi^+\pi^-$, $e^+e^- \to \phi\eta$ and $e^+e^- \to \omega\eta/\pi^0$ [29], are being finished. The current situation of the $\phi(2170)$ parameters is displayed in Fig. 6, indicating the $\phi(2170)$ remains intriguing and therefore more efforts are needed. Hopefully BESIII will provide new data in the future.

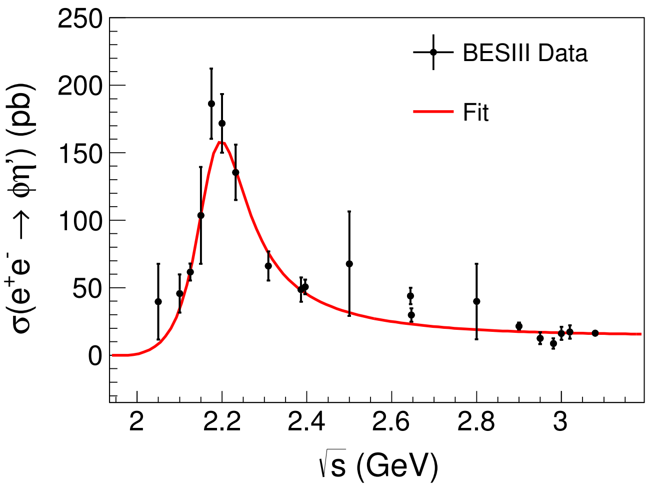

Figure 5: Born cross sections of the $e^+e^- \to \phi\eta'$ process. The solid curve (red) shows the fit to the line shape of the Born cross sections. The dots (black) with error bars show data.

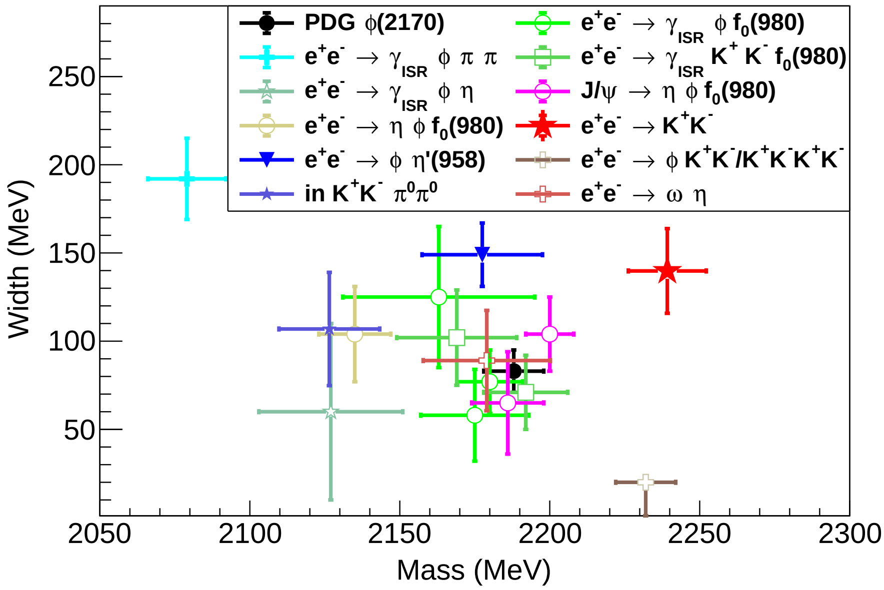

Figure 6: A compilation of measured mass and width of the $\phi(2170)$.

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