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Study of $\phi(2170)$ at BESIII

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The strangeonium state $\phi(2170)$ is studied and presented. The processes of $e^+e^- \to K^+K^-$, $e^+e^- \to K^0_S K^0_L$, $e^+e^- \to \phi K^+K^-$ $/K^+K^-K^+K^-$, $e^+e^- \to \phi\eta$, $e^+e^- \to \phi\eta'$, $e^+e^- \to K^+K^-\pi^0\pi^0$ and $e^+e^- \to \omega\eta$ are investigated. And the cross sections are measured precisely in the center-of-mass (c.m.) energy region from 2.00 to 3.08 GeV. The parameters of $\phi(2170)$ have been extracted from the lineshapes where applicable.

Keywords: Hadronic spectrum; strangeonium; $\phi(2170)$.

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1. Introduction

Hadron spectroscopy is the subfield of particle physics that studies the masses and decays of hadrons and it is also an important part of the new nuclear physics. The research of quarkonium is one of the significant aspect of hadron spectroscopy. In the past decades, charmonium ($c\bar{c}$) and bottomonium ($b\bar{b}$) states have been abundantly studied, and provide rigorous tests of QCD. The strangeonium ($s\bar{s}$) states, the strange companions, would behave in an analogous way [1]. The spectrum of strangeonium has not been founded completely up to now, both in theory predictions and in experimental observations. 22 $s\bar{s}$ resonances are expected, however only near half of them are identified. Attributable to the smaller mass of the s quark, the strangeonium states are exceedingly crowded at lower energy region, and mixed with hybrids, glueballs and other exotics are the possible reasons. BESIII has the capabilities to achieve a direct investigation for strangeonium states in between. The $\phi(2170)$ is an ideal target.

The first observation of the $\phi(2170)$ meson was reported by the *BABAR* Collaboration in the initial-state-radiation (ISR) process $e^+e^- \to \gamma_{ISR}\phi\pi^+\pi^-$ [2]. The *BABAR* [3–5], BES [6], Belle [7] and BESIII [8–15] Collaborations also studied $\phi(2170)$ decays. Nevertheless, the information is miscellaneous, and even the measured masses and widths of $\phi(2170)$ are contentious. The discovery of the $\phi(2170)$ has sparked extensive discussions about its internal structure. Proposed explanations include: a $s\bar{s}g$ hybrid state [16–19], either the 2^3D_1 [20–23] or 3^3S_1 [24, 25] $s\bar{s}$ state, a $s\bar{s}s\bar{s}$ tetraquark state [26–34], a $\Lambda\bar{\Lambda}$ molecular state [35–40], a $\phi f_0(980)$ resonance [32, 41–43] including final state interaction effects [8, 44], a S-wave threshold effect [44], and a $X(2240)$ state [45]. The situation cannot be clarified without further experimental data.

BESIII has collected about 650 pb^{-1} at 22 energies from 2.00 to 3.08 GeV taken in 2015. The world-leading data sample for precision measurements provides an excellent experimental platform to study the $\phi(2170)$ decays.

2. Results of $\phi(2170)$ research at BESIII

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

The cross section lineshape of the process $e^+e^- \to K^+K^-$ is measured, with a resonant structure with mass $(2239.2 \pm 7.1(\text{sta}) \pm 11.3(\text{sys}))$ MeV/c^2, width $(139.8 \pm 12.3 \pm 20.6)$ MeV is observed, as shown in Fig. 1 [9].

The result is consistent with the measurement in the process $e^+e^- \to \gamma\pi^+\pi^-$ [47], which is not used in the world average.

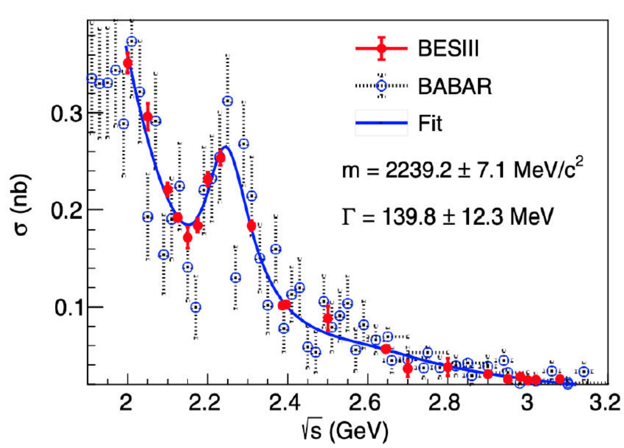

FIGURE 1. Born cross section ($\sigma^{\text{Born}} = N_{\text{signal}}/\mathcal{L}\epsilon(1+\delta)$) of the $e^+e^- \to K^+K^-$ process. For the detail of the fit see the Ref [9].

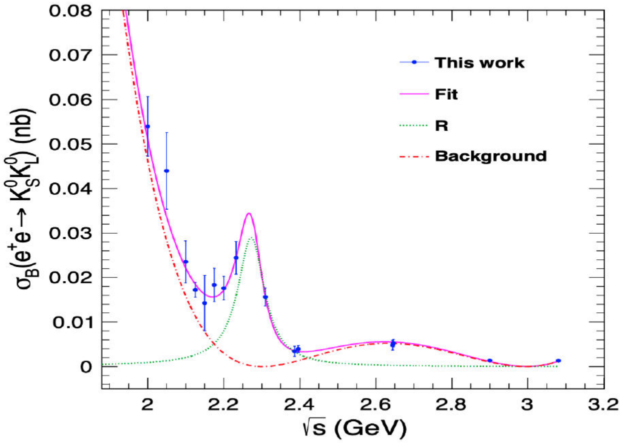

FIGURE 2. Born cross section of the $e^+e^- \to K_S^0K_L^0$ process [15].

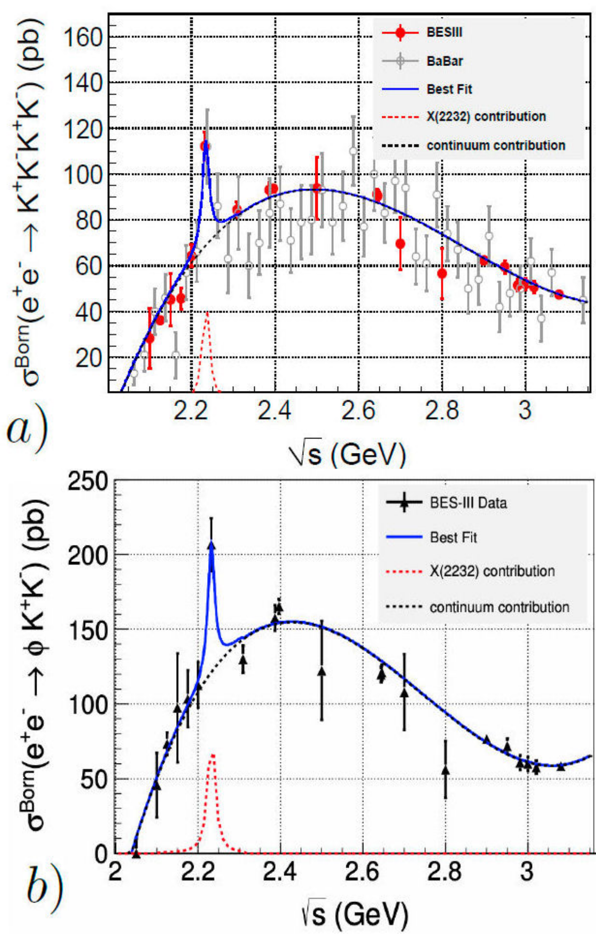

FIGURE 3. The measured Born cross section of the a) $e^+e^- \to K^+K^-K^+K^-$ and b) $e^+e^- \to \phi K^+K^-$ [10].

2.2. $e^+e^- \to K_S^0K_L^0$

The cross section lineshape of the process $e^+e^- \to K_S^0K_L^0$ is measured, with a resonant structure with mass $(2273.7 \pm 5.7 \pm 19.3)$ MeV/c^2, width $(86 \pm 44 \pm 51)$ MeV is observed from a Breit-Wigner shape fitting, as shown in Fig. 2 [15]. The partial width of $e^+e^- \to K_S^0K_L^0$ is found to be $(0.9 \pm 0.6 \pm 0.7)$ eV. The mass and width are consistent with the individual measurement of the process $e^+e^- \to \gamma\pi^+\pi^-$ [47].

2.3. $e^+e^- \to \phi K^+K^-$ and $K^+K^-K^+K^-$

BESIII has measured the Born cross sections of the process of $e^+e^- \to K^+K^-K^+K^-$, and also its dominant sub-

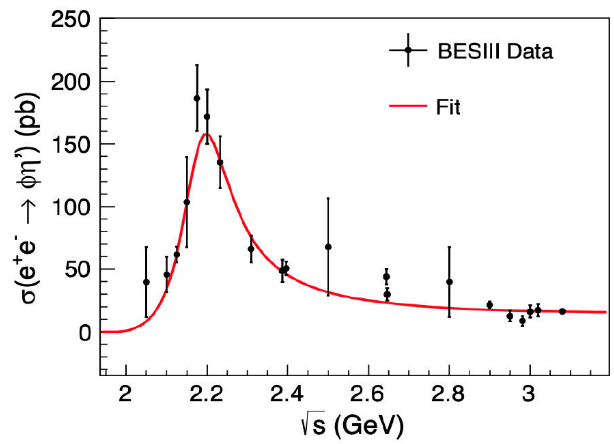

FIGURE 4. The measured Born cross section of the $e^+e^- \to \phi\eta'$ [12].

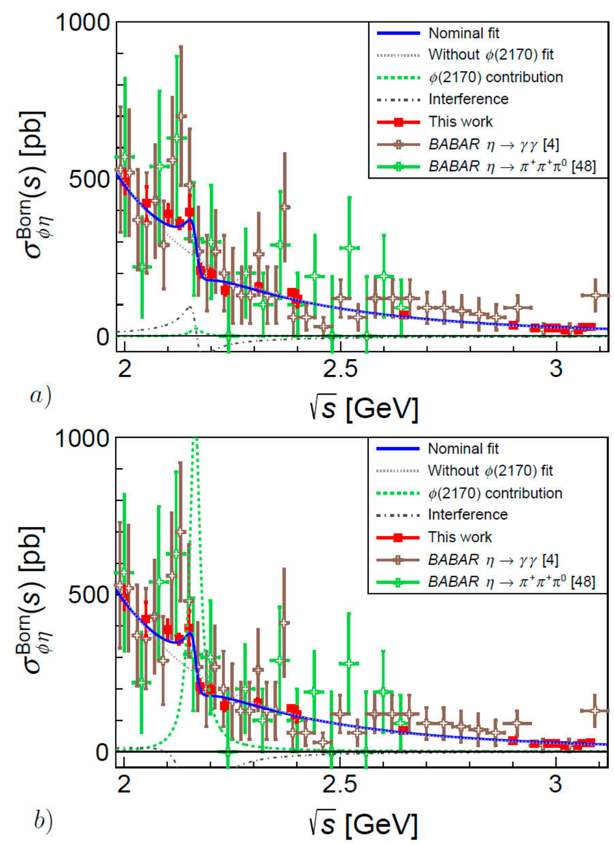

FIGURE 5. The measured Born cross section of the $e^+e^- \to \phi\eta$, the red points are BESIII data [14], a) Solution I, b) Solution II.

mode $e^+e^- \to \phi K^+K^-$, with the lineshapes illustrated in Fig. 3 [10]. An enhancement at 2.232 GeV is observed, particularly approximate to $\Lambda\bar{\Lambda}$ production threshold. The existing data could not determine if there is a resonance, and a finer scan would be needed.

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

BESIII measured the cross section of $e^+e^- \to \phi\eta'$ for the first time in detail, and a prominent resonance with mass $(2177.5 \pm 4.8 \pm 19.5)$ MeV/c^2, width $(149.0 \pm 15.6 \pm 8.9)$ MeV, partial width $(7.1 \pm 0.7 \pm 0.7)$ eV is observed in Fig. 4 [12].

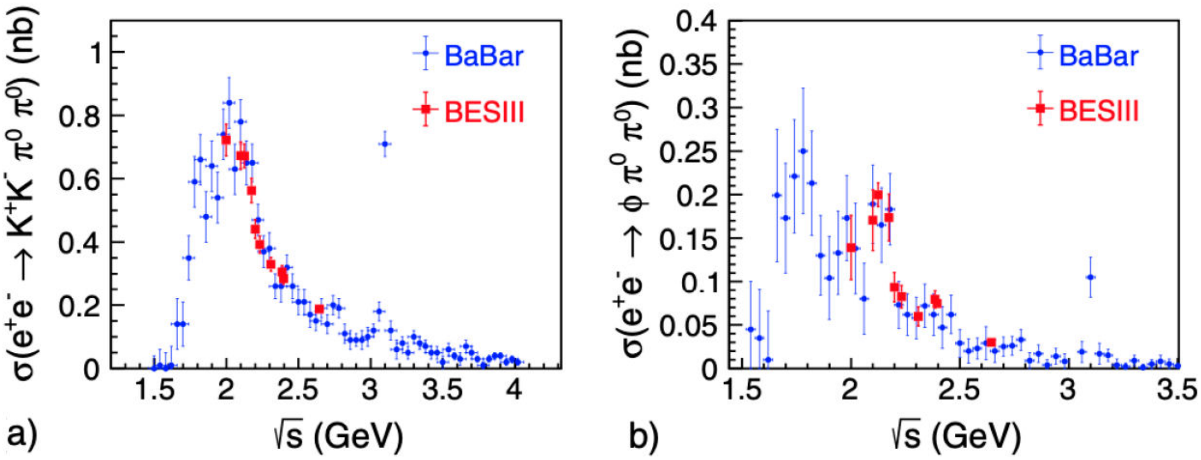

FIGURE 6. The Born cross sections for a) $e^+e^- \to K^+K^-\pi^0\pi^0$, b) $e^+e^- \to \phi\pi^0\pi^0$.

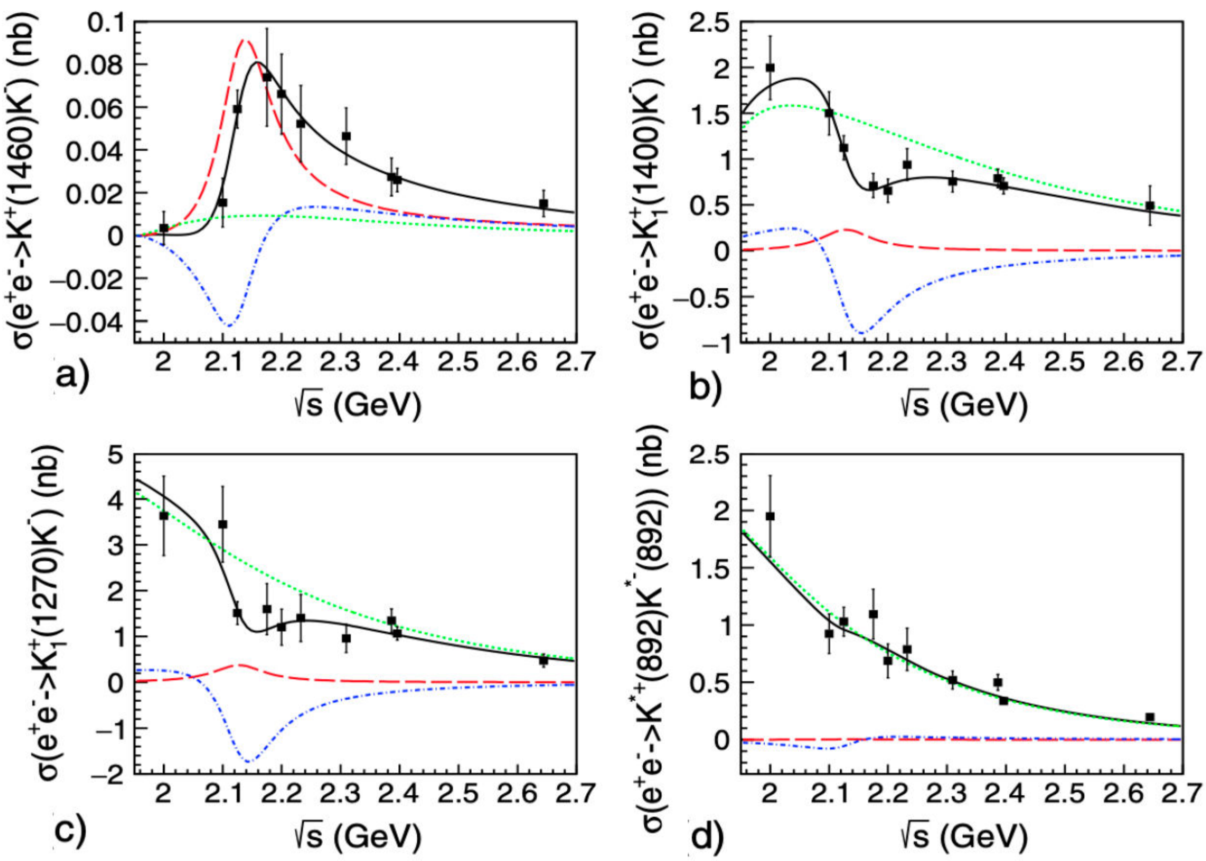

FIGURE 7. Fit to the cross sections for e^+e^- to the processes a) $K^+(1460)K^-$, b) $K_1^+(1400)K^-$, c) $K_1^+(1270)K^-$ and d) $K^{*+}(892)$ $K^{*-}(892)$, where the black solid curves are the overall fit results, the red long-dashed curves are from the intermediate state, the green short-dashed curves are from the nonresonant component, and the blue dash-dotted curves are the interference contribution for Solution 1 [11].

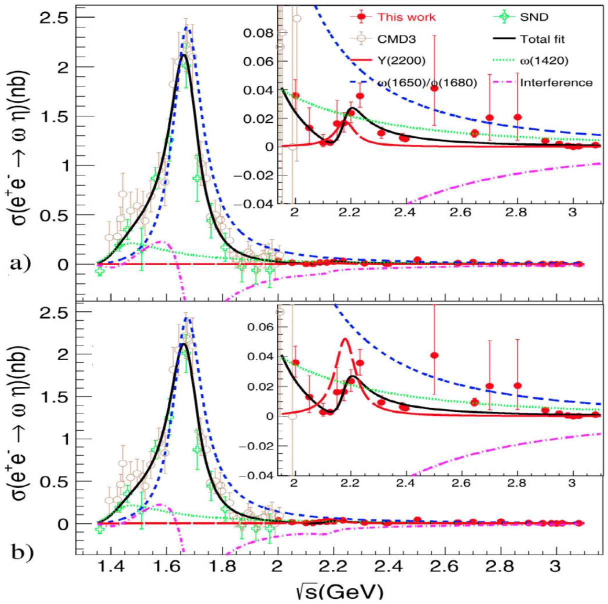

FIGURE 8. Fit to the cross sections for $e^+e^- \to \omega\eta$, a) Solution I, b) Solution II.

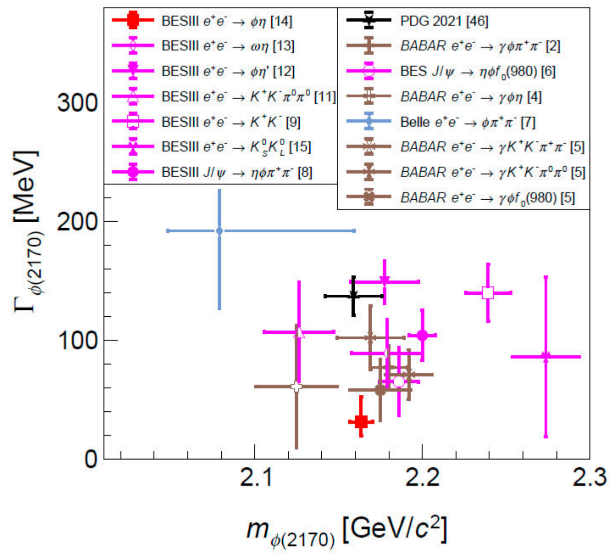

FIGURE 9. A compilation of measured mass and width of the $\phi(2170)$.

2.5. $e^+e^- \to \phi\eta$

The process $e^+e^- \to \phi\eta$ is studied at 22 energy points, the Born cross sections are measured.

A resonant structure around 2.175 GeV is observed with a significance of 6.9σ with mass $(2163.5 \pm 6.2 \pm 3.0)$ MeV/c^2, width $(31.1^{+21.1}_{-11.6} \pm 1.1)$ MeV and partial width $(0.24^{+0.12}_{-0.07})$ or $(10.11^{+3.87}_{-3.13})$ eV, illustrated in Fig. 5 [14]. The observed structure is compatible with the $\phi(2170)$, and thus the ratio of partial width between $\phi\eta$ and $\phi\eta'$ by BESIII is

$$\frac{\mathcal{B}^{\phi(2170)}_{\phi\eta}\Gamma^{\phi(2170)}_{e^+e^-}}{\mathcal{B}^{\phi(2170)}_{\phi\eta'}\Gamma^{\phi(2170)}_{e^+e^-}} = \left(0.03^{+0.02}_{-0.01}\right) \text{ or } \left(1.42^{+0.56}_{-0.46}\right).$$

This is smaller than the prediction of the $s\bar{s}g$ hybrid models by several orders of magnitude [16–19], and casts severe doubt on the validity of these models.

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

A partial-wave analysis is performed for the process $e^+e^- \to K^+K^-\pi^0\pi^0$, and various sub-processes were carefully examined [11]. A anticipated resonance around 2.1 GeV is observed from the lineshape of the sub-mode $e^+e^- \to \phi\pi^0\pi^0$ in Fig. 6b).

By analyzing the cross sections for the four subprocesses, $K^+(1460)K^-$, $K_1^+(1400)K^-$, $K_1^+(1270)K^-$, and $K^{*+}(892)K^{*-}(892)$, a structure with mass $(2126.5 \pm 16.8 \pm 12.4)$ MeV/c^2, width $(106.9 \pm 32.1 \pm 28.1)$ MeV is observed with an overall statistical significance of 6.3σ, illustrated in Fig. 7. The results are not consistent with any of the existing theoretical models.

2.7. $e^+e^- \to \omega\eta$

Born cross sections for the processes $e^+e^- \to \omega\eta$ is measured, a resonance with a mass of $(2176 \pm 24 \pm 3)$ MeV/c^2, width $(89 \pm 50 \pm 5)$ MeV is observed with a significance of 6.2σ in Fig. 8 [13].

The observed structure agrees well with the properties of the $\phi(2170)$ resonance, which indicates the first observation of the decay $\phi(2170) \to \omega\eta$.

3. Summary

BESIII has advanced measurements of various of processes. These experimental results contribute profitable information in comprehension of the $\phi(2170)$. Additional investigations, such as $e^+e^- \to \phi\pi^+\pi^-$ are being accomplished. The summary of the results of $\phi(2170)$ parameters is listed in Fig. 9, demonstrating that the $\phi(2170)$ remains fascinating, and consequently more endeavour is required. BESIII would provide captivating results in the future.

*Speaker

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