PROCEEDINGS OF SCIENCE

Study of $\phi(2170)$ at BESIII

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Beijing Spectrometer (BESIII) is the leading experiment in operation in the field of $\tau - c$ physics, that provides opportunity to study QCD properties in the transition region between non-perturbative and perturbative aspects as well. BESIII has found new hadronic states in study of the charmonium spectroscopy, which leads to interest in the new states in strange quark sector. Among experimental observables, an intriguing particle is the $\phi(2170)$ resonance. To address properties of the resonance, exclusive processes are investigated to check its decay patterns. Here some of the $\phi(2170)$ related studies are discussed, including $K\bar{K}$, $\phi\eta$, $\phi\eta'$, $\omega\eta$, $K^+K^-\pi^+\pi^-$, and $K^+K^-K^+K^-$ final states.

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1. Introduction

Quarkonia provide a unique platform to study QCD. Substantial progress has been made over the recent years from the investigation of charmonia ($c\bar{c}$) and bottomonia ($b\bar{b}$). The properties of states in charmonium and bottomonium spectroscopy are fine investigated. Meanwhile, a plethora of interesting new hadronic states were found, which have similar property but not fill exactly in the spectroscopies, like $Z_c(3900)$,$Y(4260)$, and so on. New types of hadronic matter, such as hybrids, multiquark states, and hadronic molecules with (hidden) charm and bottom quarks are considered in the interpretations. The multitude of results from heavier quarkonia leads to the obvious question whether similar states exist in the strange sector. However, experimental evidence for a rich spectrum of strangeonium ($s\bar{s}$) or new types of hadronic matter with strange quarks is scarce. A candidate for an exotic type of hadronic matter containing strange quarks is the $\phi(2170)$ resonance. It was first observed by BABAR and then confirmed by BES and BELLE. Its mass is around 2100 MeV/c^2, but with a width, ~ 80 MeV, which is quite narrow compared to other excited ϕ states. Theorists explain it as a traditional 3^3S_1 $s\bar{s}$ or 2^3D_1 $s\bar{s}$ state [1], as a 1^{--} $s\bar{s}g$ hybrid [2], as a tetraquark state [3], as a $\Lambda\bar{\Lambda}$ bound state [4], and as a ϕKK resonance state [5]. The nature of the $\phi(2170)$ resonance is still unclear, and its decay patterns are needed to distinguish various models. The BESIII experiment has made efforts to address such question.

2. BESIII experiment

The BEPCII is a symmetric electron positron collider, creating data on or off resonances in the designed energy region from the center-of-mass energy $\sqrt{s}$ = 2.0 to 4.9 GeV [6]. The BESIII detector is a magnetic spectrometer located at the BEPCII, containing a multilayer drift chamber, a time-of-flight detector, an electromagnetic calorimeter, a superconducting magnet and a moun identifier. The detailed structure and performance of the detector are described in Ref. [7]. The BESIII has been taking data since 2009 for physics. In the study of the $\phi(2170)$ resonance, the main data set is located in 2.0 and 3.08 GeV with an integrated luminosity more than 600 pb^{-1}.

3. Selected BESIII results on $\phi(2170)$

At BESIII, several exclusive processes have been studied to investigate the properties of the $\phi(2170)$ resonance. Since it is supposed to contain strange quarks and the lightest meson containing strange quark is kaon, the $e^+e^- \to K\bar{K}$ processes are studied in the energy region from 2.0 to 3.08 GeV [8, 9]. In Ref. [8], the cross section of the $e^+e^- \to K^+K^-$ process is measured with much improved accuracy compared to BABAR's results [10, 11]. A clear resonance is observed around 2.2 GeV 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. The resonance may be contributed by both $\phi(2170)$ and $\rho(2150)$ states. The parameters obtained from K^+K^- line shape differ from the world average parameters of $\phi(2170)$ and $\rho(2150)$ states by more than 3σ in mass and 2σ in width. In Ref. [9], the cross section of the $e^+e^- \to K_SK_L$ process is reported in the same energy region. There is also a structure around 2.2 GeV with the mass and width of the resonance determined to be $m = 2273.7 \pm 5.7 \pm 19.3$ MeV/c^2 and $\Gamma = 86 \pm 44 \pm 51$ MeV, which is consistent with the observation in the K^+K^- case.

As the $\phi(2170)$ state is supposed to be a member of ϕ states, it would decay to the ground state ϕ and a scaler particle. One of such researches is the $e^+e^- \to \phi\eta$ process studied in energy between 2.00 and 3.08 GeV [12], which show a resonance around 2.2 GeV with significance larger than 6.9σ. The parameters of the resonance are determined to be $m = 2163.5 \pm 6.2 \pm 3.0$ MeV$/c^2$ and $\Gamma = 31.1^{+21.1}_{-11.6} \pm 1.1$ MeV. A similar process, $e^+e^- \to \phi\eta'$, is also studied in energy region from 2.05 to 3.08 GeV [13]. A resonance is observed with mass $m = 2177.5 \pm 4.8 \pm 19.5$ MeV/c^2 and width $\Gamma = 149.0 \pm 15.6 \pm 8.9$ MeV with a statistical significance larger than 10σ.

The cross section of the $e^+e^- \to \omega\eta$ process is reported this year in energy region from 2.00 to 3.08 GeV [14]. One resonant structure is observed with a significance of 6.2σ in the cross section lineshape of the $e^+e^- \to \omega\eta$ process, with mass $m = 2176 \pm 24 \pm 3$ MeV$/c^2$, width $\Gamma = 89 \pm 50 \pm 5$ MeV. The observed structure agrees well with the properties of the $\phi(2170)$ resonance, which indicates the first observation of the decay $\phi(2170) \to \omega\eta$.

Theoretically, the $e^+e^- \to K\bar{K}\pi\bar{\pi}$ processes are more powerful in the judgement of models, since plenty of intermediate processes can be extracted from these processes to compare with the predictions of models. A partial wave analysis is performed on the process $e^+e^- \to K^+K^-\pi^0\pi^0$ at the center-of-mass energies ranging from 2.000 to 2.644 GeV [15]. In the analysis, the subprocesses $e^+e^- \to \phi\pi^0\pi^0$, $K^+(1460)K^-$, $K_1^+(1400)K^-$, $K_1^+(1270)K^-$, and $K^{*+}(892)K^{*-}(892)$ are extracted. The results of $e^+e^- \to K^+K^-\pi^0\pi^0$ and $\phi\pi^0\pi^0$ are consistent with those of BABAR with better precision, and show enhancement around 2.15 GeV. By analyzing the $K^+(1460)K^-$, $K_1^+(1400)K^-$, $K_1^+(1270)K^-$, and $K^{*+}(892)K^{*-}(892)$ processes, 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 is observed with an overall significance of 6.3σ. The significances in $K^+(1460)K^-$ and $K_1^+(1400)K^-$ channels are larger than 4σ, while less than 2σ in the latter two subprocesses $K_1^+(1270)K^-$, and $K^{*+}(892)K^{*-}(892)$. Based on the partial widths determined for those intermediate processes, the theoretical expectations from 3^3S_1 $s\bar{s}$, 2^3D_1 $s\bar{s}$ and the hybrid states do not agree well with the experimental results.

Another four-body process, $e^+e^- \to K^+K^-K^+K^-$, is also reported in 2019, as well as the $e^+e^- \to \phi K^+K^-$ process [16]. An enhancement at $\sqrt{s} = 2.232$ GeV is observed in the cross section lineshapes of both processes, which is very close to the $\Lambda\bar{\Lambda}$ threshold. If the enhancement is due to a resonance, the width would be less than 20 MeV. The intriguing $\phi(2170)$ resonance has a relatively wider width, which is not suitable in the explanation of the anomaly.

4. Summary and discussion

Figure 1 summarizes BESIII results on the $\phi(2170)$ resonance, as well as results from others experiments. The results are not in good agreement with each other. PDG 2020 [17] only provided a range that cover most of the results. With the BESIII inputs, PDG updated the world average values of its mass and width.

Strangenium is terra incognita to be explored. BESIII has contributed a lot of information in two-body and multi-body final states processes, and more results are expected to be reported. Those information can help to reveal the property of the $\phi(2170)$ resonance. In the further, we may need studies in more processes and theoretical works are also highly desired to explain the results in different modes.

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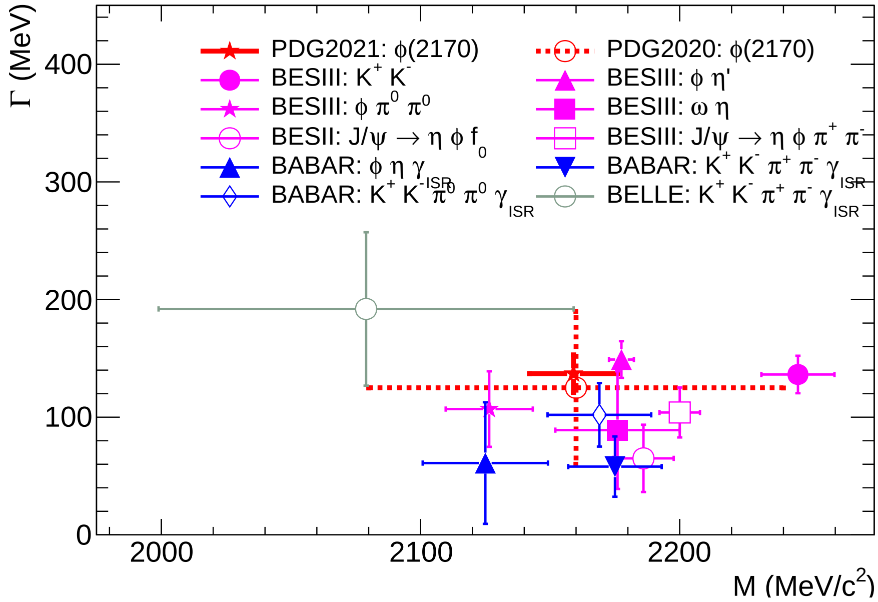

Figure 1: Mass and width of ϕ(2170)-related resonant structures measured in different processes.

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