Preliminary Result of the ψ(3686)→ϕϕϕ(ϕϕω)

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Using a sample of $441 \cdot 10^6\,\psi(3686)$ events produced in e^+e^- collisions at $\sqrt{s} = 3.686\,GeV$ and collected with the BESIII detector at the BEPCII collider, we present studies of the decays $\psi(3686) \to \phi\phi\phi$ and $\phi\phi\omega$. We observe the ϕ and ω signals, around $780\,MeV$ and $1020\,MeV$ with significances of 3.19σ and 2.74σ, respectively. The branching fractions of $\psi(3686) \to \phi\phi\phi$ and $\phi\phi\omega$ with subsequent decay $\phi \to K^+K^-$ are measured for the first time.

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INTRODUCTION

The quark model, an outstanding achievement of the last century, provides a rather good description of the hadron spectrum. However, baryon spectroscopy is far from complete, since many of the states expected in the SU(3) multiplets are either undiscovered or not well es-tablished [1]. At present, only 7 $(s\bar{s})$ states have been experimentally established. Further investigation of their properties, e.g. mass, width and spin-parity, is important to the under-standing of ϕ states. In e^+e^- annihilation, double charmonium production may help establish the $\eta_c(2S)$ state and observed cross section of $J/\psi(c\bar{c})\sim10$ times larger than the NRQCD theoretical predictions. Start of $e^+e^- \to (s\bar{s})(s\bar{s})$ may help explore new $(s\bar{s})$ states and understand $(c\bar{c})(c\bar{c})$ puzzle.

Furthermore, our knowledge of charmonium decays into hadrons, especially to $\phi\phi\phi$ and $\phi\phi\omega$ decays, is limited. The precise measurements of the branching fractions of charmonium decays may help provide a better understanding of the decay mechanism. The large ψ(3686) data sample collected with the BESIII detector provides a good opportunity to study to $\phi\phi\phi$ and $\phi\phi\omega$ decays.

In this paper, we report on a study of the decays $\psi(3686) \to \phi\phi\phi$ and $\phi\phi\omega$ based on a sample of $1.06 \cdot 10^6\,\psi(3686)$ events collected with the BESIII detector.

DETECTOR AND MONTE-CARLO SIMULATION

BESIII is a major upgrade of the BESII experiment at the BEPCII accelerator for studies of hadron spectroscopy as well as τ-charm physics [2]. BEPCII is a two-ring collider designed for a luminosity of $10^{33} cm^{-2} s^{-1}$ at the ψ' resonance with a beam current of $0.93A$. The BESIII detector has a geometrical acceptance of 93% of 4π, and consists of a helium-gas-based drift chamber (MDC), a plastic scintillator time-of-flight system (TOF), a CsI(Tl) electromagnetic calorimeter (EMC), a superconducting solenoid magnet providing $1.0T$ magnetic field, and a resistive plate chamber-based muon chamber (MUC). The momentum resolution of charged particles at $1\,GeV/c$ is 0.5%. The time resolution of the TOF is 80 ps in the barrel detector and 110 ps in the end cap detectors. The photon energy resolution at $1\,GeV$ is 2.5% (5%) in the barrel (end caps) of the EMC. The trigger system is designed to accommodate data taking at high luminosity. A comprehensive description of the BEPCII collider and the BESIII detector is given in Ref. [3].

A GEANT4-based [4] MC simulation software BOOST [5], which includes geometric and material description of the BESIII detector, detector response and digitization models as well as tracking of the detector running condition and performance, is used to generate MC samples. A series of exclusive MC samples, $\psi(3686) \to \phi\phi\phi$ and $\phi\phi\omega$ with subsequent decay $\phi \to K^+K^-$ are generated to optimize the selection criteria and estimate the corresponding detection efficiencies. The production of ψ' is simulated by the generator KKMC [6, 7]. The subsequent decays are generated with BesEvtGen [8] with a uniform distribution in phase space. An inclusive MC sample, consisting of $441 \cdot 10^6\ \psi'$ events, is used to study potential backgrounds, where the known decay modes of ψ(3686) are generated by BesEvtGen with branching fractions at world average values [9], and the remaining unknown decay modes are modeled by LUNDCHARM [10].

EVENT SELECTION

The decays $\psi(3686) \to \phi\phi\phi$ and $\phi\phi\omega$ are reconstructed from the decays $\phi \to K^+K^-$. At least four charged tracks are required and their polar angles θ must satisfy $cos\theta < 0.93$. The combined TOF anddE/dx information is used to form particle identification (PID) confidence levels for pion, kaon

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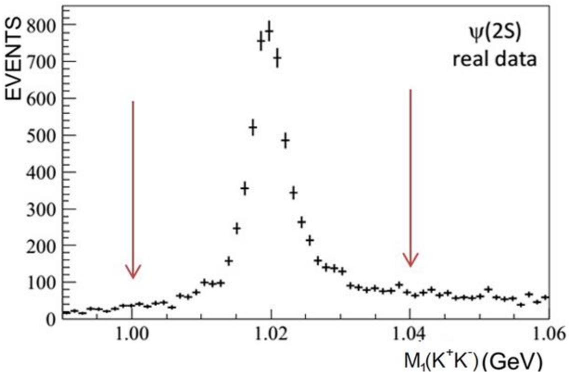
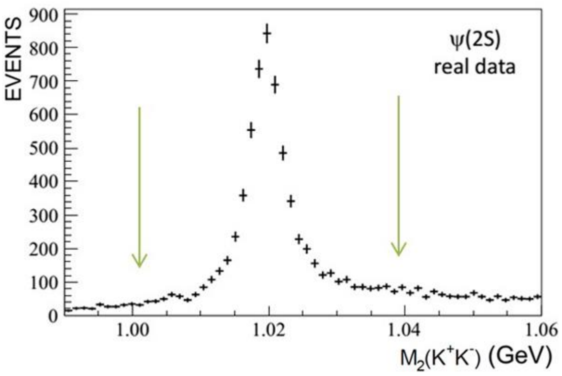
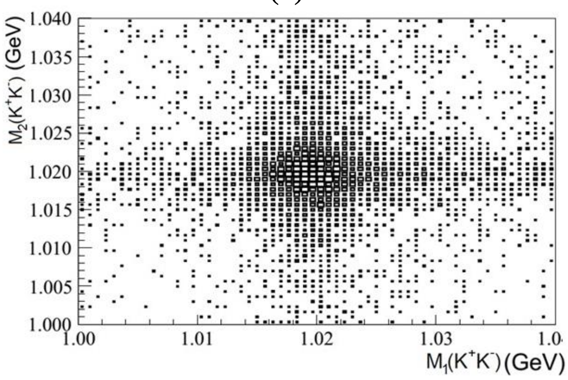
and proton hypotheses. Each track is assigned to the particle hypothesis type with the highest confidence level. Candidate events are required to have one kaon. If more than one kaon candidate is identified, only the kaon with highest confidence level is kept, and the others are assumed to be pions. The final identified charged kaon is further required to originate from the interaction point (IP), i.e., the point of its closest approach to the beam is within 1 cm in the plane perpendicular to beam and within $\pm 10\ cm$ along the beam direction. In the analysis, two ϕ particles are reconstructed and the K^+K^- combination with the minimum $|M(K^+K^-) - M(\phi)|$ is selected, where $M(K^+K^-)$ is the invariant mass of the ϕ



(a)



(b)



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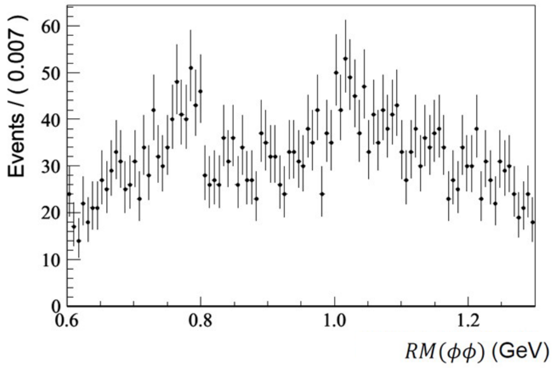

(d)

FIG. 1. The invariant mass distribution of (a) $M_1(K^+K^-)$, (b) $M_2(K^+K^-)$. Dots with error bars are data and the arrows indicate the selection requirements used in the analysis (see text). (c) The scatter plot of $M_1(K^+K^-)$ versus $M_2(K^+K^-)$ for data and the recoiling mass distribution of (d) $RM(\phi\phi)$ where significant ϕ and ω signals are observed in the data.

SIGNAL EXTRACTION

Signal yields are extracted using unbinned maximum likelihood fits to the observed distribution of the mass recoiling against $RM(\phi\phi)$ is shown in Figure 1(d). The following formula has been used for the fit:

$$\sum_{i=o}^{2} BW(m; M_i; \Gamma_i) \otimes G(m, \sigma_i) + BG \quad (1)$$

where $BW(m; M_i; \Gamma_i)$ is the Breit-Wigner function for the natural line shape of the ϕ and ω resonances, BG represents the background shape and is described by a second order Chebychev polynomial, and $G(m_i; \sigma_i)$ is a modified Gaussian function parameterizing the instrumental mass resolution, which was used by ZEUS Collaboration in ref [10] and expressed by:

$$G(m_i; \sigma_i) = \frac{1}{\sqrt{2\pi}\sigma_i} e^{-\left(\left|\frac{m}{\sigma_i}\right|\right)^{1+\left(\frac{1}{1+\left|\frac{m}{\sigma_i}\right|}\right)}} \quad (2)$$

In the fit, the natural widths of the ϕ and ω signals are fixed to the PDG [9] values, while their masses and corresponding instrumental resolutions are floated.

The overall fit result and the background components from the fit are shown as the solid and dashed curves in Figure. 2, respectively. The resulting signal yields, upper limits of signal yields, detection efficiency as well as the corresponding significances of the ϕ and ω signals, are summarized in Table I, where the significance is evaluated by comparing the difference of log-likelihood values with and without the ϕ and ω signals included in the fit and taking the change of the number of degrees of freedom into consideration. The resonance parameters from the PDG [9] are also listed in Table I for comparison. The exclusive MC samples of $\psi(3686) \to \phi\phi\phi$ and $\phi\phi\omega$ with subsequent decay $\phi \to K^+K^-$ used to determine the detection efficiencies. The detection efficiencies of the ϕ and ω signals are calculated by $\varepsilon = N^{fit}/N^{gen}$, where N^{fit} is the number of signals extracted from the fit, and N^{gen} is the number of generated signals.

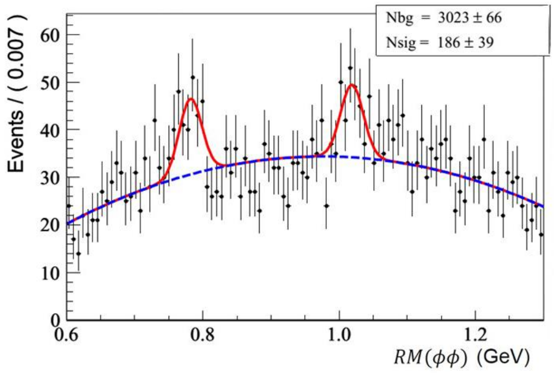

FIG. 2. Fit results projected to the recoiling mass distribution $RM(\phi\phi)$. Dots with error bars are data. The solid line is the total fit results, and the dashed line is the background contribution, respectively.

BRANCHING FRACTIONS

The branching fractions of $\psi(3686) \to \phi\phi\phi$ and $\phi\phi\omega$ are calculated according to:

$$Br = \frac{N_{up}}{(1-\sigma_{sys}) \cdot N_{\psi'} \cdot \varepsilon \cdot Br(\phi \to K^+K^-) \cdot Br(\phi \to K^+K^-)}$$

where $N_{\psi'} = 441 \cdot 10^6$ is the number of ψ' events determined with inclusive hadronic events [12], N_{up} is the upper limit of signal events, $Br(\phi \to K^+K^-)$ is the branching fraction of $\phi \to K^+K^-$ as quoted in the PDG, and ε is the detection efficiency, evaluated from the exclusive MC sample in phase-space. The uncertainty is statistical only. The results are summarized in Table I.

TABLE I. The ϕ and ω signals fit results, where the uncertainty is statistical only. The Br denotes the branching fraction $(\psi(3686) \to \phi\phi\phi)$ and $Br(\psi(3686) \to \phi\phi\omega)$.

	ϕ	ω
Signal yields	93 ± 34	69 ± 23
Upper limits	148	113
Significance (σ)	2.74	3.19
Efficiency (%)	10.89 ± 0.089	20.13 ± 0.127
$Br(10^{-5})$	0.765 ± 0.063	1.096 ± 0.103
M_{PDG}(MeV)	1019.45 ± 0.02	782.65 ± 0.12
Γ_{PDG}(MeV)	4.26 ± 0.04	8.49 ± 0.08

SYSTEMATIC UNCERTAINTY

Several sources of systematic uncertainties are considered in the measurement of the branching fractions. These include differences between data and the MC simulation for the tracking algorithm, the particle identification (PID), the fitting procedure, and mass window requirement.

a. Tracking efficiency and PID

In the analysis, according to existing results in Charm group, we assign 1.0 % as the uncertainty in tracking efficiency and PID to be conservative. Therefore, a 4% uncertainty is taken as the systematic uncertainty for the final states including $K^+K^-K^+K^-$.

b. The fitting procedure

As described above, the yields of the ϕ and ω signals are derived from fits to the mass recoiling distribution of $RM(\phi\phi)$. The fit uncertainties in the $\psi(3686) \to \phi\phi\phi$ and $\phi\phi\omega$ decays are determined by changing the fit range and background shapes. *Mass resolution:* To evaluate the systematic effects associated with this aspect, the mass recoiling distribution of $RM(\phi\phi)$ in the MC samples are smeared with a Gaussian function, where the width of this Gaussian is zero. The uncertainty is estimated from difference between mass resolution determined from fit to MC and is a value of range within (0.001,0.1). *Background shape:* To estimate the uncertainties due to the background parameterizations, a second order instead of a third order Chebychev polynomial is applied in the fitting. Again, the difference between the two cases is used as an estimate of the systematic uncertainty.

c. Mass window requirement

The uncertainty due to the phi mass window is estimated with a control sample of $J/\psi \to \eta\phi$ and is studied by comparing the phi selection efficiency obtained in the inclusive MC and the data. The uncertainty is 2.1%.

In Table II a summary of all contributions to the systematic error is shown. In each case, the total systematic uncertainty is obtained by adding the individual contributions.

SUMMARY

Using 441· 10^6 $\psi(3686)$ events collected with the BESIII detector, the process of $\psi(3686) \to \phi\phi\phi$ and $\phi\phi\omega$ are studied for the first time. In the decays $\psi(3686) \to \phi\phi\phi$ and $\phi\phi\omega$, the branching fractions measured and two signals, around 780MeV and 1020MeV are observed in the recoiling mass distribution $RM(\phi\phi)$ with significances of 3.19σ and 2.74σ, respectively. The fitted resonance parameters are consistent with those of ϕ and ω in the PDG [9] within one standard deviation. The results are summarized in Table III, where for each branching fraction the first error is statistical and the second error is systematic. The measurements improve the existing knowledge of the ϕ and ω states and may help in the understanding of the charmonium decay mechanism.

TABLE II. Summary of all systematic errors (%) .

Items	$\phi\phi\phi$	$\phi\phi\omega$
Tracking	4.0	4.0
PID	4.0	4.0
Fitting method	0.16	0.49
Mass window requirement	2.1	2.1
Total	6.03	6.05

TABLE III. The branching fraction with statistical and systematic errors.

Items	$\phi\phi\phi$	$\phi\phi\omega$
$Br(10^{-5})$	$0.765 \pm 0.063 \pm 0.046$	$1.096 \pm 0.103 \pm 0.066$

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