

RECEIVED: April 8, 2025

REVISED: May 18, 2025

ACCEPTED: May 27, 2025

PUBLISHED: June 25, 2025

Observation of $\psi(3686) \rightarrow \Xi^- K_S^0 \bar{\Omega}^+ + \text{c.c.}$



The BESIII collaboration

E-mail: besiii-publications@ihep.ac.cn

ABSTRACT: Using a sample of $(2.712 \pm 0.014) \times 10^9$ $\psi(3686)$ events collected with the BESIII detector at the electron positron collider BEPCII, the decay $\psi(3686) \rightarrow \Xi^- K_S^0 \bar{\Omega}^+ + \text{c.c.}$ is observed for the first time, which has a significance of 5.9 standard deviations. The branching fraction of this decay is measured to be $(2.91 \pm 0.47 \pm 0.33) \times 10^{-6}$, where the first and second uncertainties are statistical and systematic, respectively. The ratio between $\mathcal{B}_{\psi(3686) \rightarrow \Xi^- K_S^0 \bar{\Omega}^+ + \text{c.c.}}$ and $\mathcal{B}_{\psi(3686) \rightarrow \Omega^- K^+ \bar{\Xi}^0 + \text{c.c.}}$ is determined to be $1.05 \pm 0.23 \pm 0.14$, which deviates from the isospin symmetry conservation predicted value of 0.5 by 2.1σ .

KEYWORDS: Branching fraction, e^+e^- Experiments, Quarkonium

ARXIV EPRINT: [2504.04420](https://arxiv.org/abs/2504.04420)

Contents

1	Introduction	1
2	BESIII detector and Monte Carlo simulation	2
3	Event selection	3
4	Detection efficiency	4
5	Background study	5
6	Signal yield and BF	6
7	Systematic uncertainty	6
8	Summary	8
	The BESIII collaboration	12

1 Introduction

The discovery of the J/ψ and other charmonium(-like) states significantly impacts the development of the theory of strong interaction within the Standard Model [1, 2]. It revealed the existence of the fourth quark, known as the charm quark, while also motivating the exploration of additional heavy quarks in experimental studies. Charmonium decays serve as a critical testing ground for probing non-perturbative Quantum Chromodynamics (QCD) properties in experimental studies. [3].

The decay modes of the charmonium states to $B\bar{B}'P$, where B/B' denote a baryon and P is a pseudoscalar meson, are the important modes to search for the excited baryons and provide essential information for investigating many topics involving the strong interaction, such as the color octet and singlet contributions, the violation of helicity conservation, and SU(3) flavor symmetry breaking effects [3–5]. Under the quantum number and energy conservation, all the $B\bar{B}'P$ decays of charmonium states can be summarized straightforwardly, but the branching fractions (BFs) of them are hard to predict theoretically due to the non-perturbative strong effects at low energies [4]. In investigations of baryon strong interaction dynamics through charmonium decay processes, the production of at least two baryons is fundamentally required by baryon number conservation. To probe low-energy baryon excited states, the inclusion of an additional pseudoscalar meson becomes experimentally advantageous due to its relatively low mass. Furthermore, three-body decays typically exhibit larger BFs and simpler dynamics compared to higher-multi-body decays (four-body or five-body decays). Therefore, the studies of $B\bar{B}'P$ decays of charmonium states in experiments have become a necessary task.

Recently, the first observation of the decay $\psi(3686) \rightarrow \Xi^0 K^- \bar{\Omega}^+ + c.c.$ has been reported and the corresponding BF has been measured by the BESIII collaboration [5]. This study expanded our knowledge of the decay mechanism of $\psi(3686)$ and provided an ideal environment to search for possible Ξ^* and Ω^* states [6, 7]. The research of its isospin partner channels

can also search for the possible baryon excited states and test the $SU(3)$ flavor symmetry, which is interesting.

In this paper, the first observation of the decay $\psi(3686) \rightarrow \Xi^- K_S^0 \bar{\Omega}^+ + c.c.$ is reported and the corresponding BF is measured using $(2.712 \pm 0.014) \times 10^9$ $\psi(3686)$ events [8] collected with the BESIII detector. In addition, the possible baryon excited states are searched for and the conservation of isospin symmetry is tested in this decay. Throughout this paper, the charge-conjugate mode is always implied.

2 BESIII detector and Monte Carlo simulation

The BESIII detector [9] records symmetric e^+e^- collisions provided by the BEPCII storage ring [10] in the center-of-mass energy range from 1.84 to 4.95 GeV, with a peak luminosity of $1.1 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$ achieved at $\sqrt{s} = 3.773$ GeV. BESIII has collected large data samples in this energy region [11, 12]. The cylindrical core of the BESIII detector covers 93% of the full solid angle and consists of a helium-based multilayer drift chamber (MDC), a time-of-flight system (TOF), and a CsI(Tl) electromagnetic calorimeter (EMC), which are all enclosed in a superconducting solenoidal magnet providing a 1.0 T magnetic field. The solenoid is supported by an octagonal flux-return yoke with resistive plate counter muon identification modules interleaved with steel. The charged-particle momentum resolution at 1 GeV/c is 0.5%, and the dE/dx resolution is 6% for electrons from Bhabha scattering. The EMC measures photon energies with a resolution of 2.5% (5%) at 1 GeV in the barrel (end cap) region. The time resolution in the plastic scintillator TOF barrel region is 68 ps, while that in the end cap region was 110 ps. The end cap TOF system was upgraded in 2015 using multigap resistive plate chamber technology, providing a time resolution of 60 ps, which benefits 83% of the data used in this analysis [13–15].

Monte Carlo (MC) simulated data samples produced with a GEANT4 [16] based software package, which includes the geometric description of the BESIII detector and the detector response, are used to optimize the event selection criteria, estimate the signal efficiency and background level. The simulations incorporate the beam-energy spread and initial-state radiation in the e^+e^- annihilation using the generator KKMC [17]. The inclusive MC sample includes the production of the $\psi(3686)$ resonance, the initial-state radiation production of the J/ψ meson, and the continuum processes incorporated in KKMC [17]. Particle decays are generated by EVTGEN [18, 19] for the known decay modes with BFs taken from the Particle Data Group [20] and LUNDCHARM [21, 22] for the remaining unknown ones. Final-state radiation from charged final-state particles is included using the PHOTOS package [23]. The inclusive MC sample at the $\psi(3686)$ resonance, consisting of 2.712×10^9 events, is analysed with a generic event-type examination tool, TopoAna [24], to identify potential backgrounds. To determine the detection efficiency, a signal MC sample comprising 2 million events of the signal decay chain of $\psi(3686) \rightarrow \Xi^- K_S^0 \bar{\Omega}^+, \Xi^- \rightarrow \Lambda(\rightarrow p\pi^-)\pi^-, K_S^0 \rightarrow \pi^+\pi^-$ is generated uniformly distributed in phase space, along with inclusive $\bar{\Omega}^+$ decays. The data sample collected at the center-of-mass energies of 3.650 and 3.773 GeV, corresponding to total integrated luminosities of 410 pb^{-1} and 7.93 fb^{-1} [25], are used to estimate the continuum production contribution. The data sample of $(2.712 \pm 0.014) \times 10^9$ $\psi(3686)$ events is used to study $\psi(3686) \rightarrow \Xi^- K_S^0 \bar{\Omega}^+$.

3 Event selection

As the full reconstruction method suffers from low detection efficiency, a partial-reconstruction strategy is applied, in which only the Ξ^- and K_S^0 candidates are reconstructed, without identifying $\bar{\Omega}^+$. The cascade decay of interest is $\psi(3686) \rightarrow \Xi^- K_S^0 \bar{\Omega}^+$, with $\Xi^- \rightarrow \Lambda \pi^-$, $\Lambda \rightarrow p \pi^-$ and $K_S^0 \rightarrow \pi^+ \pi^-$. Charged tracks detected in the MDC are required to be within a polar angle (θ) range of $|\cos\theta| < 0.93$, where θ is defined with respect to the z -axis, which is the symmetry axis of the MDC. For these tracks, the distance of closest approach to the interaction point (IP) is required to be less than 20 cm along the MDC axis. Particle identification (PID) for charged tracks combines measurements of the energy deposited in the MDC (dE/dx) and the flight time in the TOF to form likelihoods $\mathcal{L}(h)$ ($h = p, K, \pi$) for each hadron h hypothesis. Tracks are identified as protons when the proton hypothesis has the greatest likelihood ($\mathcal{L}(p) > \mathcal{L}(K)$ and $\mathcal{L}(p) > \mathcal{L}(\pi)$), while charged pions are identified by comparing the likelihoods for the kaon and pion hypotheses, $\mathcal{L}(\pi) > \mathcal{L}(K)$. PID is performed for the proton from Λ and the pion from Ξ^- . The pion from Λ can be effectively identified through the vertex fit of Λ , whereas the selection of pion from Ξ^- through vertex fit of Ξ^- is not satisfactory. PID applied on the pion from Ξ^- can suppress the background of misidentification of it.

The Λ candidates are reconstructed using vertex fits [26] on $p\pi^-$ pairs with the requirement $\chi^2 < 200$. The $p\pi^-$ invariant mass ($M_{p\pi^-}$) must be within the Λ signal region, $M_{p\pi^-} \in [1.111, 1.120] \text{ GeV}/c^2$, as shown in figure 1(a). The signal region corresponds to six times the Λ mass resolution, as determined by fitting the distribution of $M_{p\pi^-}$ for the signal MC sample.

The Ξ^- candidate is reconstructed with a Λ candidate and a π^- by another vertex fit. The d_{Ξ^-} , which is the decay length of the Ξ^- obtained by the vertex fit, is required to be larger than 0. If there is more than one Ξ^- candidate, the one with the minimum $\sqrt{\left(\frac{M_{\Lambda\pi^-} - M_{\Xi^-}^{\text{PDG}}}{\sigma_{M_{\Lambda\pi^-}}}\right)^2 + \left(\frac{M_{p\pi^-} - M_{\Lambda}^{\text{PDG}}}{\sigma_{M_{p\pi^-}}}\right)^2}$ is chosen, where $M_{\Xi^-}^{\text{PDG}}$ and M_{Λ}^{PDG} are the nominal masses of Ξ^- and Λ cited from the Particle Data Group [20]. $\sigma_{M_{\Lambda\pi^-}}$ and $\sigma_{M_{p\pi^-}}$ are the mass resolution of Ξ^- and Λ , which is 2.8 and 1.5 MeV/ c^2 respectively. The invariant mass of the Ξ^- candidate is defined as $M_{\Xi^-} = M_{\Lambda\pi^-} - M_{p\pi^-} + M_{\Lambda}^{\text{PDG}}$, which is used to improve the mass resolution of the Ξ^- candidate. The distribution of M_{Ξ^-} is shown in figure 1(b). The Ξ^- signal region is defined as $M_{\Xi^-} \in [1.313, 1.330] \text{ GeV}/c^2$, corresponding to six times the Ξ^- mass resolution determined by fitting the distribution of M_{Ξ^-} for the signal MC sample. The sideband regions defined as $M_{\Xi^-} \in ([1.296, 1.305] \cup [1.339, 1.347]) \text{ GeV}/c^2$ are used to investigate the background.

Each K_S^0 candidate is reconstructed from two oppositely charged tracks satisfying $|V_z| < 20 \text{ cm}$. The two charged tracks are assigned as $\pi^+ \pi^-$ without imposing further PID criteria. They are constrained to originate from a common vertex. The decay length of the K_S^0 candidate is required to be greater than twice the vertex resolution away from the IP. The quality of the vertex fits is ensured by a requirement on the χ_{st}^2 and χ_{nd}^2 ($\chi_{st}^2 < 200$ and $\chi_{nd}^2 < 200$), which χ_{st}^2 and χ_{nd}^2 are the Chi-Square of primary and secondary vertex fit, respectively. The distribution of $M_{\pi^+ \pi^-}$ is shown in figure 1(c). The K_S^0 signal region is defined as $M_{\pi^+ \pi^-} \in [0.489, 0.506] \text{ GeV}/c^2$, corresponding to six times the K_S^0 mass resolution determined by fitting the distribution of $M_{\pi^+ \pi^-}$ for the signal MC sample. The

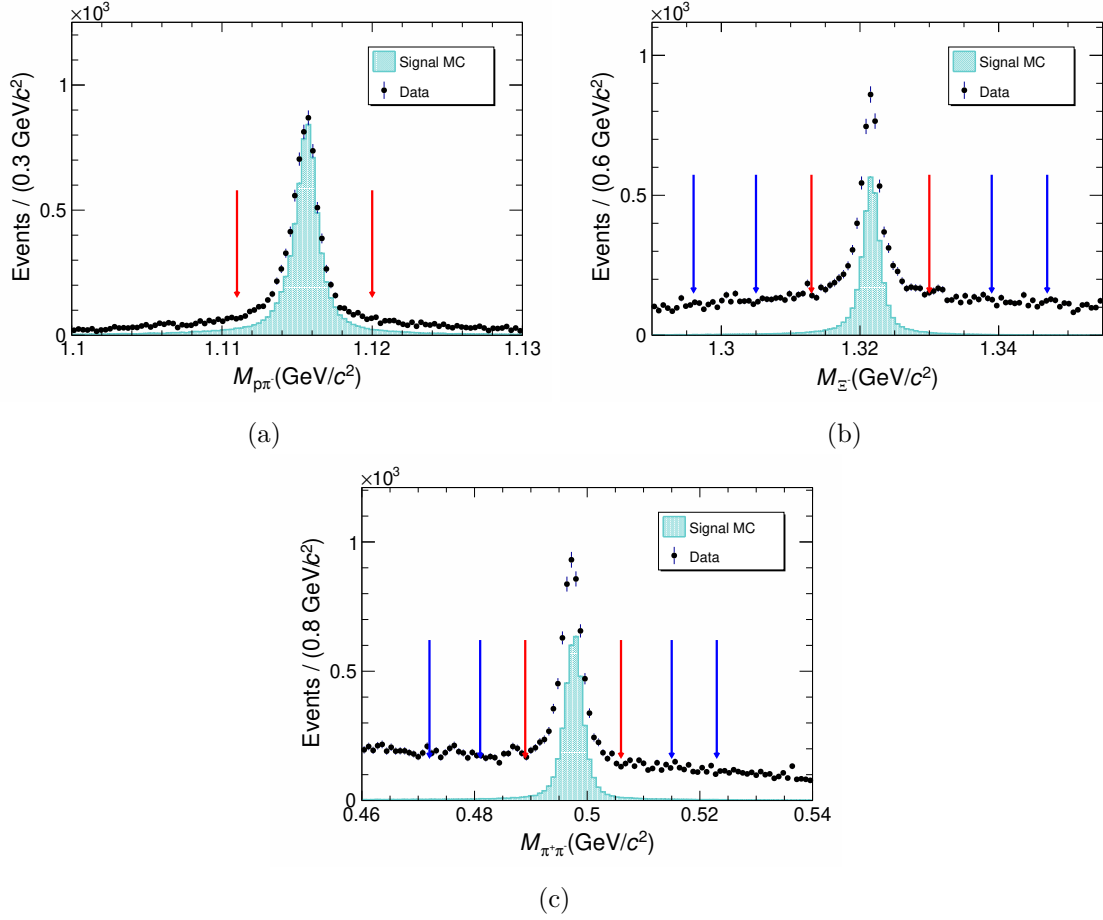


Figure 1. The distributions of $M_{p\pi^-}$ (a), M_{Ξ^-} (b) and $M_{\pi^+\pi^-}$ (c) for the data and signal MC sample. The red arrows show the signal region, and the blue arrows show the sideband regions.

sideband regions defined as $M_{\pi^+\pi^-} \in ([0.472, 0.481] \cup [0.515, 0.523]) \text{ GeV}/c^2$ are used to study the background.

Signal events manifest themselves through an $\bar{\Omega}^+$ peak in the distribution of the invariant mass recoiling against the $\Xi^- K_S^0$ system ($RM_{\Xi^- K_S^0}$), $RM_{\Xi^- K_S^0} = \sqrt{|p_{e^+e^-} - p_{\Xi^-} - p_{K_S^0}|^2}$, where $p_{e^+e^-}$, p_{Ξ^-} and $p_{K_S^0}$ refer to the 4-momentum of the initial e^+e^- , Ξ^- and K_S^0 .

4 Detection efficiency

The detection efficiency is determined with signal MC simulation. Thus, it is necessary to assess the potential impact of intermediate states on the efficiency. As shown in figure 2 exemplarily, which provides the Dalitz plot for the signal regions, no intermediate state, Ω^{*-} ($\Xi^- K_S^0$) or $\bar{\Xi}^{*+}$ ($\bar{\Omega}^+ K_S^0$), is evident in the data sample. Therefore, the efficiency determined by the signal MC simulation is acceptable. The diagonal band observed in the Dalitz plot of the signal MC arises from the requirement of the recoil mass of K_S^0 ($RM_{\pi^+\pi^-}$) to veto the process $\psi(3686) \rightarrow \pi^+\pi^- J/\psi$. $RM_{\pi^+\pi^-}$ is defined as $RM_{\pi^+\pi^-} = \sqrt{|p_{e^+e^-} - p_{K_S^0}|^2}$. The specific requirement will be mentioned in the section 5. In contrast, this band does not appear in the Dalitz plot of the data due to the influence of background effects.

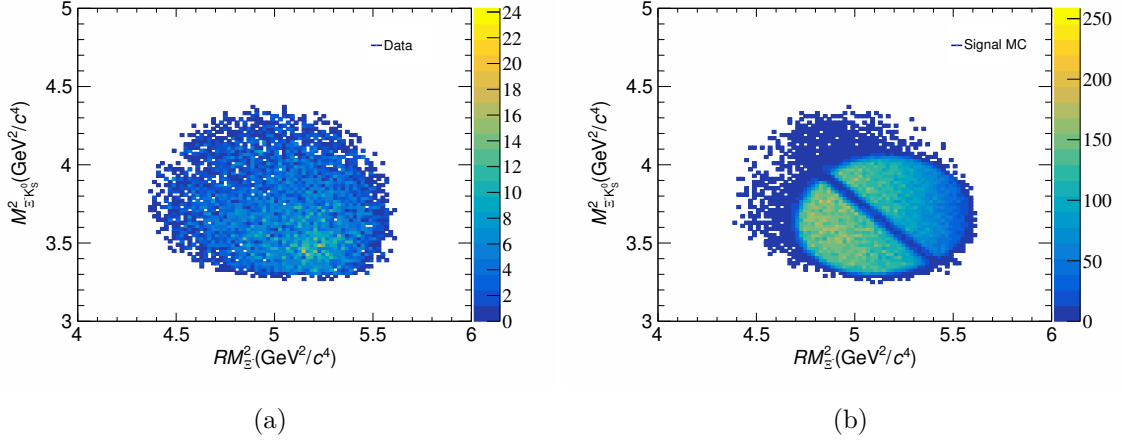


Figure 2. The Dalitz plot in the signal regions for the data (a) and signal MC sample (b).

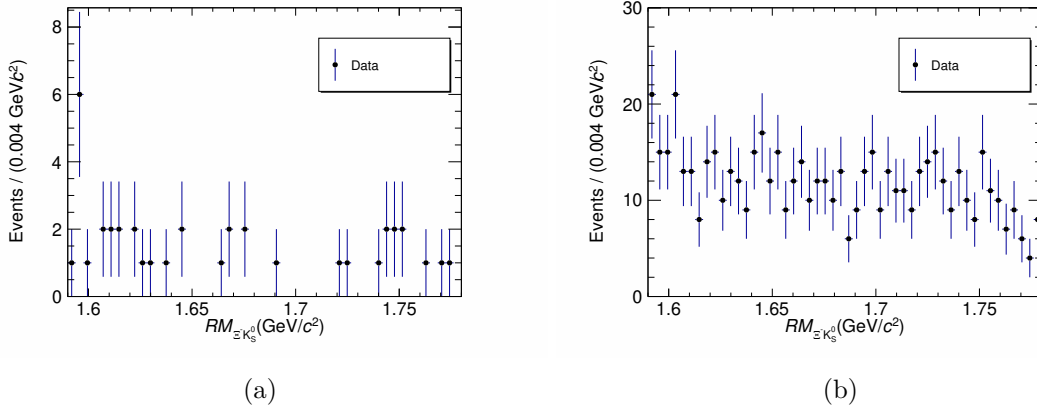


Figure 3. The distributions of $RM_{\Xi-K_S^0}$ for the data at the center-of-mass energies $\sqrt{s} = 3.650$ GeV (a) and $\sqrt{s} = 3.773$ GeV (b).

5 Background study

According to the study of the inclusive MC sample, there are peaking J/ψ background events in the recoiling mass distribution against $K_S^0(RM_{\pi^+\pi^-})$, which is from the $\psi(3686) \rightarrow \pi^+\pi^- J/\psi$ process. We require $RM_{\pi^+\pi^-}$ to be less than $3.09 \text{ GeV}/c^2$ or larger than $3.105 \text{ GeV}/c^2$ to veto such background.

Further studies are performed on the surviving events in the $\bar{\Omega}^+$ signal region from the inclusive MC sample, on the events in the Ξ^- mass sideband regions from data, and on the events in the K_S^0 sideband regions from data. These investigations indicate that there is no significant source of peaking background in the $RM_{\Xi-K_S^0}$ distribution. To investigate the contamination from continuum processes [8], the same selection criteria are applied to the data samples at the center-of-mass energies $\sqrt{s} = 3.650$ GeV and $\sqrt{s} = 3.773$ GeV. Few events from these sample survived and do not contribute a peaking structure, which are shown in figure 3, indicating the continuum background neglected.

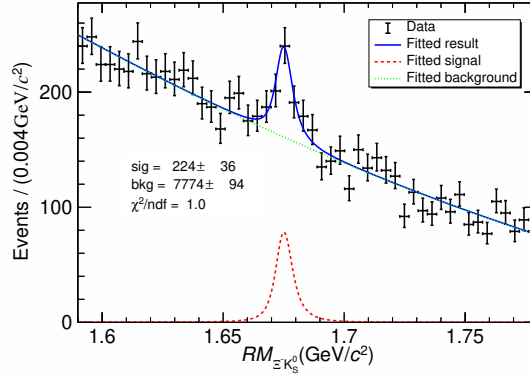


Figure 4. Fit to the $RM_{\Xi^- K_S^0}$ distribution of the accepted candidates in $\psi(3686)$ data.

6 Signal yield and BF

To determine the signal yield, an unbinned maximum-likelihood fit is performed on the $RM_{\Xi^- K_S^0}$ distribution [27]. In the fit, the signal shape is described by the signal MC shape convolved with a Gaussian function with free parameters mean value and σ , where the Gaussian function is used to account for the difference in mass resolution between data and MC simulation. The signal MC shape is the $RM_{\Xi^- K_S^0}$ shape extracted from the signal MC sample by using the RooKeysPdf in RooFit toolkit [28]. The background shape is described by a second-order Chebyshev polynomial function. The fit result is shown in figure 4. The signal yield from the fit is $N_{\text{obs.}} = 224 \pm 36$. The statistical significance of the $\bar{\Omega}^+$ signal is 6.1σ , which is determined from the change in the log-likelihood values and the corresponding change in the number of degrees of freedom with and without including the signal contribution in the fit.

The BF of the $\psi(3686) \rightarrow \Xi^- K_S^0 \bar{\Omega}^+$ decay is calculated as

$$\mathcal{B}_{\psi(3686) \rightarrow \Xi^- K_S^0 \bar{\Omega}^+} = \frac{N_{\text{obs.}}}{N_{\psi(3686)} \cdot \mathcal{B}_{\Xi^- \rightarrow \Lambda \pi^-} \cdot \mathcal{B}_{\Lambda \rightarrow p \pi^-} \cdot \mathcal{B}_{K_S^0 \rightarrow \pi^+ \pi^-} \cdot \epsilon}, \quad (6.1)$$

where $N_{\psi(3686)}$ is the total number of $\psi(3686)$ events [8], and $\epsilon = 6.43\%$ is the detection efficiency. The efficiency uncertainty is considered as a systematic uncertainty, which is estimated in the section 7. $\mathcal{B}_{\Xi^- \rightarrow \Lambda \pi^-}$, $\mathcal{B}_{\Lambda \rightarrow p \pi^-}$ and $\mathcal{B}_{K_S^0 \rightarrow \pi^+ \pi^-}$ are the BFs of $\Xi^- \rightarrow \Lambda \pi^-$, $\Lambda \rightarrow p \pi^-$ and $K_S^0 \rightarrow \pi^+ \pi^-$ decays, respectively, cited from the PDG [20]. With these inputs, the BF of $\psi(3686) \rightarrow \Xi^- K_S^0 \bar{\Omega}^+$ is determined to be $(2.91 \pm 0.47) \times 10^{-6}$, where the uncertainties is statistical.

7 Systematic uncertainty

The systematic uncertainties in the $\mathcal{B}_{\psi(3686) \rightarrow \Xi^- K_S^0 \bar{\Omega}^+}$ measurement include contributions associated with the pion-tracking, PID, Λ reconstruction, the requirement on M_{Ξ^-} and d_{Ξ^-} , $\psi(3686) \rightarrow \pi^+ \pi^- J/\psi$ veto, K_S^0 reconstruction, signal and background shapes, fit bias, MC generator, the size of signal MC sample, the input BFs [20], and the total number of $\psi(3686)$ events [8].

The systematic uncertainties arising from the pion-tracking and PID are studied with the well understood decays $J/\psi \rightarrow p\bar{p}\pi^+\pi^-$ [29] and $\psi' \rightarrow \gamma\chi_{cJ}, \chi_{cJ} \rightarrow \gamma\rho^0(\omega)$ [30], and both are assigned as 1.0% per track.

The systematic uncertainty associated with the Λ -reconstruction includes effects from the tracking and PID for the proton and the tracking for pion, and the requirement on $M_{p\pi^-}$. This uncertainty is estimated with a control sample of $J/\psi \rightarrow pK^-\bar{\Lambda}$ decays [31, 32]. The momentum-dependent ratios of the Λ reconstruction efficiencies between data and MC simulation are used to re-weight the signal MC sample. The difference between the baseline and reweighted detection efficiencies, 2.7%, is taken as the systematic uncertainty.

The systematic uncertainties associated with the requirements on M_{Ξ^-} and d_{Ξ^-} are studied with a control sample of $J/\psi \rightarrow \Xi^-\bar{\Xi}^+$, where Ξ^- is fully reconstructed with $\Xi^- \rightarrow \Lambda\pi^-$, $\Lambda \rightarrow p\pi^-$. The reconstruction strategy for Ξ^- is the same as in section 3 and the uncertainty is determined to be 0.2%.

The $\psi(3686) \rightarrow \pi^+\pi^-J/\psi$ background is vetoed by requiring $RM_{\pi^+\pi^-}$ to be less than 3.09 GeV/ c^2 or more than 3.105 GeV/ c^2 . By changing the requirement of $RM_{\pi^+\pi^-}$ to be less than 3.08 GeV/ c^2 or more than 3.115 GeV/ c^2 , the change of the re-measured BF, 2.4%, is assigned as the systematic uncertainty.

Two control samples $J/\psi \rightarrow K^*(892)^-K^+, K^*(892)^- \rightarrow K_S^0\pi^-$ and $J/\psi \rightarrow \phi K_S^0 K^+\pi^-$ are used to study the systematic uncertainty of K_S^0 reconstruction. By comparing the inconsistency in the data and signal MC regarding the reconstruction of K_S^0 , this uncertainty is estimated to 1.2%.

The pseudo-experiment method is used to estimate the systematic uncertainty related to the fit bias, signal shape and background shape. The probability density function (PDF) is utilized to describe the signal and background distributions derived from the fit to data. Subsequently, 500 pseudo-experiments are generated based on the same statistical properties as the real data, with the derived PDFs. The same fitting method as the nominal result is applied to perform fits on the 500 pseudo-experiments samples. The difference between the mean value of the fitted signal yields and the nominal signal yield is assigned as the systematic uncertainty of fit bias, amounting to 5.5%. To explore the impact of different signal shape models, the signal shape is modified from convolving the MC shape with a Gaussian function to convolving the MC shape with two Gaussian functions in the alternative fit model. Both the alternative and nominal fits are then applied to the 500 fake data. The distribution of the differences between the fitted signal yields with these two models describes the deviation between the two fit models. The systematic uncertainty attributed to the signal shape is quantified as the mean value of this distribution, which is 0.7%. Similarly, the background shape is modified from the second-order to first-order or third-order Chebyshev polynomial function as an alternative fit model. The systematic uncertainty attributed to the background shape is determined to be 8.8% using the same method, which is the maximum value of the two alternative fit model.

Similar to refs. [33, 34], an event-by-event weighting method is used to study the systematic uncertainty related to the MC generator. The signal MC events are weighted according to the momentum distributions of K_S^0 and Ξ^- in data. The deviation between the nominal and reweighting detection efficiencies, 1.7%, is taken as the systematic uncertainty.

Source	Uncertainty (%)
Pion tracking	1.0
Pion PID	1.0
Λ reconstruction	2.7
Mass window and decay length of Ξ^-	0.2
Veto $\psi(3686) \rightarrow \pi^+\pi^-J/\psi$	2.4
K_S^0 reconstruction	1.2
Signal shape	0.7
Background shape	8.8
Fit bias	5.5
MC generator	1.7
MC sample size	0.2
$\mathcal{B}_{\Xi^- \rightarrow \Lambda\pi^-}$	0.1
$\mathcal{B}_{K_S^0 \rightarrow \pi^+\pi^-}$	0.1
$\mathcal{B}_{\Lambda \rightarrow p\pi^-}$	0.8
Total number of $\psi(3686)$ events	0.4
Total	11.3

Table 1. Relative systematic uncertainties in the BF measurement.

The systematic uncertainty arising from the size of the signal MC sample is 0.2%, which is the uncertainty of detection efficiency. The uncertainty associated with the total number of $\psi(3686)$ events is 0.5% [8]. The uncertainties arising from the quoted BFs of $\Xi^- \rightarrow \Lambda\pi^-$, $\Lambda \rightarrow p\pi^-$ and $K_S^0 \rightarrow \pi^+\pi^-$ are 0.04%, 0.8% and 0.1% [20], respectively.

The systematic uncertainties are summarized in table 1. Assuming that all sources are independent, the total systematic uncertainty on the BF of $\psi(3686) \rightarrow \Xi^- K_S^0 \bar{\Omega}^+$ is determined to be 11.3% by adding them in quadrature.

The $\bar{\Omega}^+$ signal statistical significance is conservatively estimated to be 5.9σ after considering the systematic variations of vetoing $\psi(3686) \rightarrow \pi^+\pi^-J/\psi$, and the signal and background shapes in the fit to $RM_{\Xi^- K_S^0}$. With considering the systematic effects, the BF of $\psi(3686) \rightarrow \Xi^- K_S^0 \bar{\Omega}^+$ is determined to be $(2.91 \pm 0.47 \pm 0.33) \times 10^{-6}$, where the first uncertainty is statistical and the second is systematic.

8 Summary

In summary, using the world's largest $\psi(3686)$ data sample taken with the BESIII detector, we observe the $\psi(3686) \rightarrow \Xi^- K_S^0 \bar{\Omega}^+$ decay for the first time by employing a partial reconstruction method. The measured BF is $(2.91 \pm 0.47 \pm 0.33) \times 10^{-6}$, where the first uncertainty is statistical and the second is systematic. This result provides valuable information for understanding the dynamics of $\psi(3686) \rightarrow BB'P$ decays. Combining the BF of $\psi(3686) \rightarrow \Xi^- K_S^0 \bar{\Omega}^+$ measured in this paper and the BF of $\psi(3686) \rightarrow \Omega^- K^+ \bar{\Xi}^0$ [5], the ratio $\mathcal{R} = \frac{\mathcal{B}_{\psi(3686) \rightarrow \Xi^- K_S^0 \bar{\Omega}^+}}{\mathcal{B}_{\psi(3686) \rightarrow \Omega^- K^+ \bar{\Xi}^0}}$ is determined to be $1.05 \pm 0.23(\text{stat}) \pm 0.14(\text{syst})$, which deviates from the isospin symmetry conservation predicted value of 0.5 by 2.1σ . It is hard to make any reliable conclusion

about this deviation under the current statistics. More precise measurements of these two decays are desirable.

Acknowledgments

The BESIII Collaboration thanks the staff of BEPCII and the IHEP computing center for their strong support. This work is supported in part by National Key R&D Program of China under Contracts Nos. 2020YFA0406300, 2020YFA0406400, 2023YFA1606000; National Natural Science Foundation of China (NSFC) under Contracts Nos. 11635010, 11735014, 11935015, 11935016, 11935018, 12025502, 12035009, 12035013, 12061131003, 12165022, 12192260, 12192261, 12192262, 12192263, 12192264, 12192265, 12221005, 12225509, 12235017, 12342502, 12361141819; the China Postdoctoral Science Foundation under Grant Number 2024M753040; the Postdoctoral Fellowship Program of China Postdoctoral Science Foundation under Grant Number GZC20241608; the Chinese Academy of Sciences (CAS) Large-Scale Scientific Facility Program; the CAS Center for Excellence in Particle Physics (CCEPP); Joint Large-Scale Scientific Facility Funds of the NSFC and CAS under Contract No. U1832207; CAS under Contract No. YSBR-101; 100 Talents Program of CAS; the Beijing Natural Science Foundation under Grant Number IS23014; The Institute of Nuclear and Particle Physics (INPAC) and Shanghai Key Laboratory for Particle Physics and Cosmology; Yunnan Fundamental Research Project under Contract No. 202301AT070162; Agencia Nacional de Investigación y Desarrollo de Chile (ANID), Chile under Contract No. ANID PIA/APOYO AFB230003; German Research Foundation DFG under Contract No. FOR5327; Istituto Nazionale di Fisica Nucleare, Italy; Knut and Alice Wallenberg Foundation under Contracts Nos. 2021.0174, 2021.0299; Ministry of Development of Turkey under Contract No. DPT2006K-120470; National Research Foundation of Korea under Contract No. NRF-2022R1A2C1092335; National Science and Technology fund of Mongolia; National Science Research and Innovation Fund (NSRF) via the Program Management Unit for Human Resources & Institutional Development, Research and Innovation of Thailand under Contract No. B50G670107; Polish National Science Centre under Contract No. 2019/35/O/ST2/02907; Swedish Research Council under Contract No. 2019.04595; The Swedish Foundation for International Cooperation in Research and Higher Education under Contract No. CH2018-7756; U.S. Department of Energy under Contract No. DE-FG02-05ER41374

Data Availability Statement. This article has no associated data or the data will not be deposited.

Code Availability Statement. This article has no associated code or the code will not be deposited.

Open Access. This article is distributed under the terms of the Creative Commons Attribution License ([CC-BY4.0](https://creativecommons.org/licenses/by/4.0/)), which permits any use, distribution and reproduction in any medium, provided the original author(s) and source are credited.

References

- [1] E598 collaboration, *Experimental Observation of a Heavy Particle J* , *Phys. Rev. Lett.* **33** (1974) 1404 [INSPIRE].
- [2] SLAC-SP-017 collaboration, *Discovery of a Narrow Resonance in e^+e^- Annihilation*, *Phys. Rev. Lett.* **33** (1974) 1406 [INSPIRE].
- [3] R. Baldini Ferroli, A. Mangoni, S. Pacetti and K. Zhu, *Strong and electromagnetic amplitudes of the J/ψ decays into baryons and their relative phase*, *Phys. Lett. B* **799** (2019) 135041 [arXiv:1905.01069] [INSPIRE].
- [4] D.M. Asner et al., *Physics at BES-III*, *Int. J. Mod. Phys. A* **24** (2009) S1 [arXiv:0809.1869] [INSPIRE].
- [5] BESIII collaboration, *Observation of $\psi(3686) \rightarrow \Omega^- K^+ \Xi^0 + c.c.$* , *JHEP* **04** (2024) 013 [arXiv:2401.08252] [INSPIRE].
- [6] BESIII collaboration, *Model-Independent Determination of the Spin of the Ω^- and Its Polarization Alignment in $\psi(3686) \rightarrow \Omega^- \bar{\Omega}^+$* , *Phys. Rev. Lett.* **126** (2021) 092002 [arXiv:2007.03679] [INSPIRE].
- [7] BESIII collaboration, *Observation of the decay $\chi_{cJ} \rightarrow \Omega^- \bar{\Omega}^+$* , *Phys. Rev. D* **107** (2023) 092004 [arXiv:2302.12579] [INSPIRE].
- [8] BESIII collaboration, *Determination of the number of $\psi(3686)$ events at BESIII*, *Chin. Phys. C* **42** (2018) 023001 [arXiv:1709.03653] [INSPIRE].
- [9] BESIII collaboration, *Design and Construction of the BESIII Detector*, *Nucl. Instrum. Meth. A* **614** (2010) 345 [arXiv:0911.4960] [INSPIRE].
- [10] C. Yu et al., *BEPCII Performance and Beam Dynamics Studies on Luminosity*, in the proceedings of the 7th International Particle Accelerator Conference, Busan, South Korea, May 08–13 (2016) [DOI:10.18429/JACoW-IPAC2016-TUYA01] [INSPIRE].
- [11] BESIII collaboration, *Future Physics Programme of BESIII*, *Chin. Phys. C* **44** (2020) 040001 [arXiv:1912.05983] [INSPIRE].
- [12] J.-W. Zhang et al., *Suppression of top-up injection backgrounds with offline event filter in the BESIII experiment*, *Radiat. Detect. Technol. Methods* **6** (2022) 289 [INSPIRE].
- [13] X. Li et al., *Study of MRPC technology for BESIII endcap-TOF upgrade*, *Radiat. Detect. Technol. Methods* **1** (2017) 13 [INSPIRE].
- [14] Y.-X. Guo et al., *The study of time calibration for upgraded end cap TOF of BESIII*, *Radiat. Detect. Technol. Methods* **1** (2017) 15 [INSPIRE].
- [15] P. Cao et al., *Design and construction of the new BESIII endcap Time-of-Flight system with MRPC Technology*, *Nucl. Instrum. Meth. A* **953** (2020) 163053 [INSPIRE].
- [16] GEANT4 collaboration, *GEANT4 — A Simulation Toolkit*, *Nucl. Instrum. Meth. A* **506** (2003) 250 [INSPIRE].
- [17] S. Jadach, B.F.L. Ward and Z. Was, *Coherent exclusive exponentiation for precision Monte Carlo calculations*, *Phys. Rev. D* **63** (2001) 113009 [hep-ph/0006359] [INSPIRE].
- [18] D.J. Lange, *The EvtGen particle decay simulation package*, *Nucl. Instrum. Meth. A* **462** (2001) 152 [INSPIRE].
- [19] R.-G. Ping, *Event generators at BESIII*, *Chin. Phys. C* **32** (2008) 599 [INSPIRE].

- [20] PARTICLE DATA GROUP collaboration, *Review of particle physics*, *Phys. Rev. D* **110** (2024) 030001 [[INSPIRE](#)].
- [21] J.C. Chen et al., *Event generator for J/ψ and $\psi(2S)$ decay*, *Phys. Rev. D* **62** (2000) 034003 [[INSPIRE](#)].
- [22] R.-L. Yang, R.-G. Ping and H. Chen, *Tuning and Validation of the Lundcharm Model with J/ψ Decays*, *Chin. Phys. Lett.* **31** (2014) 061301 [[INSPIRE](#)].
- [23] E. Richter-Was, *QED bremsstrahlung in semileptonic B and leptonic tau decays*, *Phys. Lett. B* **303** (1993) 163 [[INSPIRE](#)].
- [24] X. Zhou, S. Du, G. Li and C. Shen, *TopoAna: A generic tool for the event type analysis of inclusive Monte-Carlo samples in high energy physics experiments*, *Comput. Phys. Commun.* **258** (2021) 107540 [[arXiv:2001.04016](#)] [[INSPIRE](#)].
- [25] BESIII collaboration, *Measurement of the integrated luminosities of the data taken by BESIII at $\sqrt{s}=3.650$ and 3.773 GeV*, *Chin. Phys. C* **37** (2013) 123001 [[arXiv:1307.2022](#)] [[INSPIRE](#)].
- [26] M. Xu et al., *Decay vertex reconstruction and 3-dimensional lifetime determination at BESIII*, *Chin. Phys. C* **33** (2009) 428 [[INSPIRE](#)].
- [27] BESIII collaboration, *First measurement of $e^+e^- \rightarrow pK_S^0\bar{n}K^- + \text{c.c.}$ above open charm threshold*, *Phys. Rev. D* **98** (2018) 032014 [[arXiv:1807.03468](#)] [[INSPIRE](#)].
- [28] W. Verkerke and D.P. Kirkby, *The RooFit toolkit for data modeling*, *eConf C* **0303241** (2003) MOLT007 [[physics/0306116](#)] [[INSPIRE](#)].
- [29] W.-L. Yuan et al., *Study of tracking efficiency and its systematic uncertainty from $J/\psi \rightarrow p\bar{p}\pi^+\pi^-$ at BESIII*, *Chin. Phys. C* **40** (2016) 026201 [[arXiv:1507.03453](#)] [[INSPIRE](#)].
- [30] BESIII collaboration, *Study of χ_{cJ} radiative decays into a vector meson*, *Phys. Rev. D* **83** (2011) 112005 [[arXiv:1103.5564](#)] [[INSPIRE](#)].
- [31] BESIII collaboration, *Tests of CP symmetry in entangled $\Xi^0 - \bar{\Xi}^0$ pairs*, *Phys. Rev. D* **108** (2023) L031106 [[arXiv:2305.09218](#)] [[INSPIRE](#)].
- [32] BESIII collaboration, *Strong and Weak CP Tests in Sequential Decays of Polarized Σ^0 Hyperons*, *Phys. Rev. Lett.* **133** (2024) 101902 [[arXiv:2406.06118](#)] [[INSPIRE](#)].
- [33] BESIII collaboration, *Measurements of the absolute branching fractions of Ω^- decays and test of the $\Delta I = 1/2$ rule*, *Phys. Rev. D* **108** (2023) L091101 [[arXiv:2309.06368](#)] [[INSPIRE](#)].
- [34] BESIII collaboration, *Search for $\Delta S = 2$ nonleptonic hyperon decays $\Omega^- \rightarrow \Sigma^0\pi^-$ and $\Omega^- \rightarrow nK^-$* , *JHEP* **05** (2024) 141 [[arXiv:2403.13437](#)] [[INSPIRE](#)].

The BESIII collaboration

M. Ablikim¹, M.N. Achasov^{4,c}, P. Adlarson⁷⁶, X.C. Ai⁸¹, R. Aliberti³⁵, A. Amoroso^{75A,75C},
 Q. An^{72,58,a}, Y. Bai⁵⁷, O. Bakina³⁶, Y. Ban^{46,h}, H.-R. Bao⁶⁴, V. Batozskaya^{1,44}, K. Begzsuren³²,
 N. Berger³⁵, M. Berlowski⁴⁴, M. Bertani^{28A}, D. Bettoni^{29A}, F. Bianchi^{75A,75C}, E. Bianco^{75A,75C},
 A. Bortone^{75A,75C}, I. Boyko³⁶, R.A. Briere⁵, A. Brueggemann⁶⁹, H. Cai⁷⁷, M.H. Cai^{38,k,l}, X. Cai^{1,58},
 A. Calcaterra^{28A}, G.F. Cao^{1,64}, N. Cao^{1,64}, S.A. Cetin^{62A}, X.Y. Chai^{46,h}, J.F. Chang^{1,58}, G.R. Che⁴³,
 Y.Z. Che^{1,58,64}, G. Chelkov^{36,b}, C. Chen⁴³, C.H. Chen⁹, Chao Chen⁵⁵, G. Chen¹, H.S. Chen^{1,64},
 H.Y. Chen²⁰, M.L. Chen^{1,58,64}, S.J. Chen⁴², S.L. Chen⁴⁵, S.M. Chen⁶¹, T. Chen^{1,64}, X.R. Chen^{31,64},
 X.T. Chen^{1,64}, Y.B. Chen^{1,58}, Y.Q. Chen³⁴, Z.J. Chen^{25,i}, Z.K. Chen⁵⁹, S.K. Choi¹⁰, X. Chu^{12,g},
 G. Cibinetto^{29A}, F. Cossio^{75C}, J.J. Cui⁵⁰, H.L. Dai^{1,58}, J.P. Dai⁷⁹, A. Dbeyssi¹⁸, R. E. de Boer³,
 D. Dedovich³⁶, C.Q. Deng⁷³, Z.Y. Deng¹, A. Denig³⁵, I. Denysenko³⁶, M. Destefanis^{75A,75C},
 F. De Mori^{75A,75C}, B. Ding^{67,1}, X.X. Ding^{46,h}, Y. Ding³⁴, Y. Ding⁴⁰, Y.X. Ding³⁰, J. Dong^{1,58},
 L.Y. Dong^{1,64}, M.Y. Dong^{1,58,64}, X. Dong⁷⁷, M.C. Du¹, S.X. Du⁸¹, Y.Y. Duan⁵⁵, Z.H. Duan⁴²,
 P. Egorov^{36,b}, G.F. Fan⁴², J.J. Fan¹⁹, Y.H. Fan⁴⁵, J. Fang⁵⁹, J. Fang^{1,58}, S.S. Fang^{1,64}, W.X. Fang¹,
 Y.Q. Fang^{1,58}, R. Farinelli^{29A}, L. Fava^{75B,75C}, F. Feldbauer³, G. Felici^{28A}, C.Q. Feng^{72,58},
 J.H. Feng⁵⁹, Y.T. Feng^{72,58}, M. Fritsch³, C.D. Fu¹, J.L. Fu⁶⁴, Y.W. Fu^{1,64}, H. Gao⁶⁴, X.B. Gao⁴¹,
 Y.N. Gao^{46,h}, Y.N. Gao¹⁹, Y.Y. Gao³⁰, Yang Gao^{72,58}, S. Garbolino^{75C}, I. Garzia^{29A,29B}, P.T. Ge¹⁹,
 Z.W. Ge⁴², C. Geng⁵⁹, E.M. Gersabeck⁶⁸, A. Gilman⁷⁰, K. Goetzen¹³, J.D. Gong³⁴, L. Gong⁴⁰,
 W.X. Gong^{1,58}, W. Gradl³⁵, S. Gramigna^{29A,29B}, M. Greco^{75A,75C}, M.H. Gu^{1,58}, Y.T. Gu¹⁵,
 C.Y. Guan^{1,64}, A.Q. Guo³¹, L.B. Guo⁴¹, M.J. Guo⁵⁰, R.P. Guo⁴⁹, Y.P. Guo^{12,g}, A. Guskov^{36,b},
 J. Gutierrez²⁷, K.L. Han⁶⁴, T.T. Han¹, F. Hanisch³, K.D. Hao^{72,58}, X.Q. Hao¹⁹, F.A. Harris⁶⁶,
 K.K. He⁵⁵, K.L. He^{1,64}, F.H. Heinsius³, C.H. Heinz³⁵, Y.K. Heng^{1,58,64}, C. Herold⁶⁰, T. Holtmann³,
 P.C. Hong³⁴, G.Y. Hou^{1,64}, X.T. Hou^{1,64}, Y.R. Hou⁶⁴, Z.L. Hou¹, B.Y. Hu⁵⁹, H.M. Hu^{1,64},
 J.F. Hu^{56,j}, Q.P. Hu^{72,58}, S.L. Hu^{12,g}, T. Hu^{1,58,64}, Y. Hu¹, Z.M. Hu⁵⁹, G.S. Huang^{72,58},
 K.X. Huang⁵⁹, L.Q. Huang^{31,64}, P. Huang⁴², X.T. Huang⁵⁰, Y.P. Huang¹, Y.S. Huang⁵⁹,
 T. Hussain⁷⁴, N. Hüskens³⁵, N. in der Wiesche⁶⁹, J. Jackson²⁷, S. Janchiv³², Q. Ji¹, Q.P. Ji¹⁹,
 W. Ji^{1,64}, X.B. Ji^{1,64}, X.L. Ji^{1,58}, Y.Y. Ji⁵⁰, Z.K. Jia^{72,58}, D. Jiang^{1,64}, H.B. Jiang⁷⁷, P.C. Jiang^{46,h},
 S.J. Jiang⁹, T.J. Jiang¹⁶, X.S. Jiang^{1,58,64}, Y. Jiang⁶⁴, J.B. Jiao⁵⁰, J.K. Jiao³⁴, Z. Jiao²³, S. Jin⁴²,
 Y. Jin⁶⁷, M.Q. Jing^{1,64}, X.M. Jing⁶⁴, T. Johansson⁷⁶, S. Kabana³³, N. Kalantar-Nayestanaki⁶⁵,
 X.L. Kang⁹, X.S. Kang⁴⁰, M. Kavatsyuk⁶⁵, B.C. Ke⁸¹, V. Khachatryan²⁷, A. Khoukaz⁶⁹, R. Kiuchi¹,
 O.B. Kolcu^{62A}, B. Kopf³, M. Kuessner³, X. Kui^{1,64}, N. Kumar²⁶, A. Kupsc^{44,76}, W. Kühn³⁷,
 Q. Lan⁷³, W.N. Lan¹⁹, T.T. Lei^{72,58}, M. Lellmann³⁵, T. Lenz³⁵, C. Li⁴³, C. Li⁴⁷, C.H. Li³⁹, C.K. Li²⁰,
 Cheng Li^{72,58}, D.M. Li⁸¹, F. Li^{1,58}, G. Li¹, H.B. Li^{1,64}, H.J. Li¹⁹, H.N. Li^{56,j}, Hui Li⁴³, J.R. Li⁶¹,
 J.S. Li⁵⁹, K. Li¹, K.L. Li^{38,k,l}, K.L. Li¹⁹, L.J. Li^{1,64}, Lei Li⁴⁸, M.H. Li⁴³, M.R. Li^{1,64}, P.L. Li⁶⁴,
 P.R. Li^{38,k,l}, Q.M. Li^{1,64}, Q.X. Li⁵⁰, R. Li^{17,31}, T. Li⁵⁰, T.Y. Li⁴³, W.D. Li^{1,64}, W.G. Li^{1,a}, X. Li^{1,64},
 X.H. Li^{72,58}, X.L. Li⁵⁰, X.Y. Li^{1,8}, X.Z. Li⁵⁹, Y. Li¹⁹, Y.G. Li^{46,h}, Y.P. Li³⁴, Z.J. Li⁵⁹, Z.Y. Li⁷⁹,
 C. Liang⁴², H. Liang^{72,58}, Y.F. Liang⁵⁴, Y.T. Liang^{31,64}, G.R. Liao¹⁴, L.B. Liao⁵⁹, M.H. Liao⁵⁹,
 Y.P. Liao^{1,64}, J. Libby²⁶, A. Limphirat⁶⁰, C.C. Lin⁵⁵, C.X. Lin⁶⁴, D.X. Lin^{31,64}, L.Q. Lin³⁹, T. Lin¹,
 B.J. Liu¹, B.X. Liu⁷⁷, C. Liu³⁴, C.X. Liu¹, F. Liu¹, F.H. Liu⁵³, Feng Liu⁶, G.M. Liu^{56,j}, H. Liu^{38,k,l},
 H.B. Liu¹⁵, H.H. Liu¹, H.M. Liu^{1,64}, Huihui Liu²¹, J.B. Liu^{72,58}, J.J. Liu²⁰, K. Liu^{38,k,l}, K. Liu⁷³,
 K.Y. Liu⁴⁰, Ke Liu²², L. Liu^{72,58}, L.C. Liu⁴³, Lu Liu⁴³, P.L. Liu¹, Q. Liu⁶⁴, S.B. Liu^{72,58}, T. Liu^{12,g},
 W.K. Liu⁴³, W.M. Liu^{72,58}, W.T. Liu³⁹, X. Liu^{38,k,l}, X. Liu³⁹, X.Y. Liu⁷⁷, Y. Liu^{38,k,l}, Y. Liu⁸¹,
 Y. Liu⁸¹, Y.B. Liu⁴³, Z.A. Liu^{1,58,64}, Z.D. Liu⁹, Z.Q. Liu⁵⁰, X.C. Lou^{1,58,64}, F.X. Lu⁵⁹, H.J. Lu²³,

J.G. Lu^{1,58}, Y. Lu⁷, Y.H. Lu^{1,64}, Y.P. Lu^{1,58}, Z.H. Lu^{1,64}, C.L. Luo⁴¹, J.R. Luo⁵⁹, J.S. Luo^{1,64}, M.X. Luo⁸⁰, T. Luo^{12,g}, X.L. Luo^{1,58}, Z.Y. Lv²², X.R. Lyu^{64,p}, Y.F. Lyu⁴³, Y.H. Lyu⁸¹, F.C. Ma⁴⁰, H. Ma⁷⁹, H.L. Ma¹, J.L. Ma^{1,64}, L.L. Ma⁵⁰, L.R. Ma⁶⁷, Q.M. Ma¹, R.Q. Ma^{1,64}, R.Y. Ma¹⁹, T. Ma^{72,58}, X.T. Ma^{1,64}, X.Y. Ma^{1,58}, Y.M. Ma³¹, F.E. Maas¹⁸, I. MacKay⁷⁰, M. Maggiora^{75A,75C}, S. Malde⁷⁰, Y.J. Mao^{46,h}, Z.P. Mao¹, S. Marcello^{75A,75C}, F.M. Melendi^{29A,29B}, Y.H. Meng⁶⁴, Z.X. Meng⁶⁷, J.G. Messchendorp^{13,65}, G. Mezzadri^{29A}, H. Miao^{1,64}, T.J. Min⁴², R.E. Mitchell²⁷, X.H. Mo^{1,58,64}, B. Moses²⁷, N. Yu. Muchnoi^{4,c}, J. Muskalla³⁵, Y. Nefedov³⁶, F. Nerling^{18,e}, L.S. Nie²⁰, I.B. Nikolaev^{4,c}, Z. Ning^{1,58}, S. Nisar^{11,m}, Q.L. Niu^{38,k,l}, W.D. Niu^{12,g}, S.L. Olsen^{10,64}, Q. Ouyang^{1,58,64}, S. Pacetti^{28B,28C}, X. Pan⁵⁵, Y. Pan⁵⁷, A. Pathak¹⁰, Y.P. Pei^{72,58}, M. Pelizaeus³, H.P. Peng^{72,58}, Y.Y. Peng^{38,k,l}, K. Peters^{13,e}, J.L. Ping⁴¹, R.G. Ping^{1,64}, S. Plura³⁵, V. Prasad³³, F.Z. Qi¹, H.R. Qi⁶¹, M. Qi⁴², S. Qian^{1,58}, W.B. Qian⁶⁴, C.F. Qiao⁶⁴, J.H. Qiao¹⁹, J.J. Qin⁷³, J.L. Qin⁵⁵, L.Q. Qin¹⁴, L.Y. Qin^{72,58}, P.B. Qin⁷³, X.P. Qin^{12,g}, X.S. Qin⁵⁰, Z.H. Qin^{1,58}, J.F. Qiu¹, Z.H. Qu⁷³, C.F. Redmer³⁵, A. Rivetti^{75C}, M. Rolo^{75C}, G. Rong^{1,64}, S.S. Rong^{1,64}, F. Rosini^{28B,28C}, Ch. Rosner¹⁸, M.Q. Ruan^{1,58}, S.N. Ruan⁴³, N. Salone⁴⁴, A. Sarantsev^{36,d}, Y. Schelhaas³⁵, K. Schoenning⁷⁶, M. Scodeggio^{29A}, K.Y. Shan^{12,g}, W. Shan²⁴, X.Y. Shan^{72,58}, Z.J. Shang^{38,k,l}, J.F. Shangguan¹⁶, L.G. Shao^{1,64}, M. Shao^{72,58}, C.P. Shen^{12,g}, H.F. Shen^{1,8}, W.H. Shen⁶⁴, X.Y. Shen^{1,64}, B.A. Shi⁶⁴, H. Shi^{72,58}, J.L. Shi^{12,g}, J.Y. Shi¹, S.Y. Shi⁷³, X. Shi^{1,58}, H.L. Song^{72,58}, J.J. Song¹⁹, T.Z. Song⁵⁹, W.M. Song^{34,1}, Y.X. Song^{46,h,n}, S. Sosio^{75A,75C}, S. Spataro^{75A,75C}, F. Stieler³⁵, S. S. Su⁴⁰, Y.J. Su⁶⁴, G.B. Sun⁷⁷, G.X. Sun¹, H. Sun⁶⁴, H.K. Sun¹, J.F. Sun¹⁹, K. Sun⁶¹, L. Sun⁷⁷, S.S. Sun^{1,64}, T. Sun^{51,f}, Y.C. Sun⁷⁷, Y.H. Sun³⁰, Y.J. Sun^{72,58}, Y.Z. Sun¹, Z.Q. Sun^{1,64}, Z.T. Sun⁵⁰, C.J. Tang⁵⁴, G.Y. Tang¹, J. Tang⁵⁹, L.F. Tang³⁹, M. Tang^{72,58}, Y.A. Tang⁷⁷, L.Y. Tao⁷³, M. Tat⁷⁰, J.X. Teng^{72,58}, J.Y. Tian^{72,58}, W.H. Tian⁵⁹, Y. Tian³¹, Z.F. Tian⁷⁷, I. Uman^{62B}, B. Wang⁵⁹, B. Wang¹, Bo Wang^{72,58}, C. Wang¹⁹, Cong Wang²², D.Y. Wang^{46,h}, H.J. Wang^{38,k,l}, J.J. Wang⁷⁷, K. Wang^{1,58}, L.L. Wang¹, L.W. Wang³⁴, M. Wang⁵⁰, M. Wang^{72,58}, N.Y. Wang⁶⁴, S. Wang^{12,g}, T. Wang^{12,g}, T.J. Wang⁴³, W. Wang⁷³, W. Wang⁵⁹, W.P. Wang^{35,58,72,o}, X. Wang^{46,h}, X.F. Wang^{38,k,l}, X.J. Wang³⁹, X.L. Wang^{12,g}, X.N. Wang¹, Y. Wang⁶¹, Y.D. Wang⁴⁵, Y.F. Wang^{1,58,64}, Y.H. Wang^{38,k,l}, Y.L. Wang¹⁹, Y.N. Wang⁷⁷, Y.Q. Wang¹, Yaqian Wang¹⁷, Yi Wang⁶¹, Yuan Wang^{17,31}, Z. Wang^{1,58}, Z.L. Wang⁷³, Z.L. Wang², Z.Q. Wang^{12,g}, Z.Y. Wang^{1,64}, D.H. Wei¹⁴, H.R. Wei⁴³, F. Weidner⁶⁹, S.P. Wen¹, Y.R. Wen³⁹, U. Wiedner³, G. Wilkinson⁷⁰, M. Wolke⁷⁶, C. Wu³⁹, J.F. Wu^{1,8}, L.H. Wu¹, L.J. Wu^{1,64}, Lianjie Wu¹⁹, S.G. Wu^{1,64}, S.M. Wu⁶⁴, X. Wu^{12,g}, X.H. Wu³⁴, Y.J. Wu³¹, Z. Wu^{1,58}, L. Xia^{72,58}, X.M. Xian³⁹, B.H. Xiang^{1,64}, T. Xiang^{46,h}, D. Xiao^{38,k,l}, G.Y. Xiao⁴², H. Xiao⁷³, Y.L. Xiao^{12,g}, Z.J. Xiao⁴¹, C. Xie⁴², K.J. Xie^{1,64}, X.H. Xie^{46,h}, Y. Xie⁵⁰, Y.G. Xie^{1,58}, Y.H. Xie⁶, Z.P. Xie^{72,58}, T.Y. Xing^{1,64}, C.F. Xu^{1,64}, C.J. Xu⁵⁹, G.F. Xu¹, H.Y. Xu², H.Y. Xu^{67,2}, M. Xu^{72,58}, Q.J. Xu¹⁶, Q.N. Xu³⁰, W.L. Xu⁶⁷, X.P. Xu⁵⁵, Y. Xu⁴⁰, Y. Xu^{12,g}, Y.C. Xu⁷⁸, Z.S. Xu⁶⁴, H.Y. Yan³⁹, L. Yan^{12,g}, W.B. Yan^{72,58}, W.C. Yan⁸¹, W.P. Yan¹⁹, X.Q. Yan^{1,64}, H.J. Yang^{51,f}, H.L. Yang³⁴, H.X. Yang¹, J.H. Yang⁴², R.J. Yang¹⁹, T. Yang¹, Y. Yang^{12,g}, Y.F. Yang⁴³, Y.H. Yang⁴², Y.Q. Yang⁹, Y.X. Yang^{1,64}, Y.Z. Yang¹⁹, M. Ye^{1,58}, M.H. Ye⁸, Junhao Yin⁴³, Z.Y. You⁵⁹, B.X. Yu^{1,58,64}, C.X. Yu⁴³, G. Yu¹³, J.S. Yu^{25,i}, M.C. Yu⁴⁰, T. Yu⁷³, X.D. Yu^{46,h}, Y.C. Yu⁸¹, C.Z. Yuan^{1,64}, H. Yuan^{1,64}, J. Yuan⁴⁵, J. Yuan³⁴, L. Yuan², S.C. Yuan^{1,64}, Y. Yuan^{1,64}, Z.Y. Yuan⁵⁹, C.X. Yue³⁹, Ying Yue¹⁹, A.A. Zafar⁷⁴, S.H. Zeng⁶³, X. Zeng^{12,g}, Y. Zeng^{25,i}, Y.J. Zeng^{1,64}, Y.J. Zeng⁵⁹, X.Y. Zhai³⁴, Y.H. Zhan⁵⁹, A.Q. Zhang^{1,64}, B.L. Zhang^{1,64}, B.X. Zhang¹, D.H. Zhang⁴³, G.Y. Zhang¹⁹, G.Y. Zhang^{1,64}, H. Zhang^{72,58}, H. Zhang⁸¹, H.C. Zhang^{1,58,64}, H.H. Zhang⁵⁹, H.Q. Zhang^{1,58,64}, H.R. Zhang^{72,58}, H.Y. Zhang^{1,58}, J. Zhang⁵⁹,

J. Zhang⁸¹, J.J. Zhang⁵², J.L. Zhang²⁰, J.Q. Zhang⁴¹, J.S. Zhang^{12,g}, J.W. Zhang^{1,58,64},
 J.X. Zhang^{38,k,l}, J.Y. Zhang¹, J.Z. Zhang^{1,64}, Jianyu Zhang⁶⁴, L.M. Zhang⁶¹, Lei Zhang⁴²,
 N. Zhang⁸¹, P. Zhang^{1,64}, Q. Zhang¹⁹, Q.Y. Zhang³⁴, R.Y. Zhang^{38,k,l}, S.H. Zhang^{1,64},
 Shulei Zhang^{25,i}, X.M. Zhang¹, X. Y Zhang⁴⁰, X.Y. Zhang⁵⁰, Y. Zhang⁷³, Y. Zhang¹, Y.T. Zhang⁸¹,
 Y.H. Zhang^{1,58}, Y.M. Zhang³⁹, Z.D. Zhang¹, Z.H. Zhang¹, Z.L. Zhang³⁴, Z.L. Zhang⁵⁵, Z.X. Zhang¹⁹,
 Z.Y. Zhang⁴³, Z.Y. Zhang⁷⁷, Z.Z. Zhang⁴⁵, Zh. Zh. Zhang¹⁹, G. Zhao¹, J.Y. Zhao^{1,64}, J.Z. Zhao^{1,58},
 L. Zhao¹, Lei Zhao^{72,58}, M.G. Zhao⁴³, N. Zhao⁷⁹, R.P. Zhao⁶⁴, S.J. Zhao⁸¹, Y.B. Zhao^{1,58},
 Y.L. Zhao⁵⁵, Y.X. Zhao^{31,64}, Z.G. Zhao^{72,58}, A. Zhemchugov^{36,b}, B. Zheng⁷³, B.M. Zheng³⁴,
 J.P. Zheng^{1,58}, W.J. Zheng^{1,64}, X.R. Zheng¹⁹, Y.H. Zheng^{64,p}, B. Zhong⁴¹, X. Zhong⁵⁹,
 H. Zhou^{35,50,o}, J.Q. Zhou³⁴, J.Y. Zhou³⁴, S. Zhou⁶, X. Zhou⁷⁷, X.K. Zhou⁶, X.R. Zhou^{72,58},
 X.Y. Zhou³⁹, Y.Z. Zhou^{12,g}, Z.C. Zhou²⁰, A.N. Zhu⁶⁴, J. Zhu⁴³, K. Zhu¹, K.J. Zhu^{1,58,64},
 K.S. Zhu^{12,g}, L. Zhu³⁴, L.X. Zhu⁶⁴, S.H. Zhu⁷¹, T.J. Zhu^{12,g}, W.D. Zhu^{12,g}, W.D. Zhu⁴¹, W.J. Zhu¹,
 W.Z. Zhu¹⁹, Y.C. Zhu^{72,58}, Z.A. Zhu^{1,64}, X.Y. Zhuang⁴³, J.H. Zou¹, J. Zu^{72,58}

¹ Institute of High Energy Physics, Beijing 100049, People's Republic of China

² Beihang University, Beijing 100191, People's Republic of China

³ Bochum Ruhr-University, D-44780 Bochum, Germany

⁴ Budker Institute of Nuclear Physics SB RAS (BINP), Novosibirsk 630090, Russia

⁵ Carnegie Mellon University, Pittsburgh, Pennsylvania 15213, U.S.A.

⁶ Central China Normal University, Wuhan 430079, People's Republic of China

⁷ Central South University, Changsha 410083, People's Republic of China

⁸ China Center of Advanced Science and Technology, Beijing 100190, People's Republic of China

⁹ China University of Geosciences, Wuhan 430074, People's Republic of China

¹⁰ Chung-Ang University, Seoul, 06974, Republic of Korea

¹¹ COMSATS University Islamabad, Lahore Campus, Defence Road, Off Raiwind Road, 54000 Lahore, Pakistan

¹² Fudan University, Shanghai 200433, People's Republic of China

¹³ GSI Helmholtzcentre for Heavy Ion Research GmbH, D-64291 Darmstadt, Germany

¹⁴ Guangxi Normal University, Guilin 541004, People's Republic of China

¹⁵ Guangxi University, Nanning 530004, People's Republic of China

¹⁶ Hangzhou Normal University, Hangzhou 310036, People's Republic of China

¹⁷ Hebei University, Baoding 071002, People's Republic of China

¹⁸ Helmholtz Institute Mainz, Staudinger Weg 18, D-55099 Mainz, Germany

¹⁹ Henan Normal University, Xinxiang 453007, People's Republic of China

²⁰ Henan University, Kaifeng 475004, People's Republic of China

²¹ Henan University of Science and Technology, Luoyang 471003, People's Republic of China

²² Henan University of Technology, Zhengzhou 450001, People's Republic of China

²³ Huangshan College, Huangshan 245000, People's Republic of China

²⁴ Hunan Normal University, Changsha 410081, People's Republic of China

²⁵ Hunan University, Changsha 410082, People's Republic of China

²⁶ Indian Institute of Technology Madras, Chennai 600036, India

²⁷ Indiana University, Bloomington, Indiana 47405, U.S.A.

²⁸ INFN Laboratori Nazionali di Frascati, (A)INFN Laboratori Nazionali di Frascati, I-00044, Frascati, Italy; (B)INFN Sezione di Perugia, I-06100, Perugia, Italy; (C)University of Perugia, I-06100, Perugia, Italy

²⁹ INFN Sezione di Ferrara, (A)INFN Sezione di Ferrara, I-44122, Ferrara, Italy; (B)University of Ferrara, I-44122, Ferrara, Italy

³⁰ Inner Mongolia University, Hohhot 010021, People's Republic of China

³¹ Institute of Modern Physics, Lanzhou 730000, People's Republic of China

³² Institute of Physics and Technology, Peace Avenue 54B, Ulaanbaatar 13330, Mongolia

³³ Instituto de Alta Investigación, Universidad de Tarapacá, Casilla 7D, Arica 1000000, Chile

³⁴ Jilin University, Changchun 130012, People's Republic of China

- ³⁵ *Johannes Gutenberg University of Mainz, Johann-Joachim-Becher-Weg 45, D-55099 Mainz, Germany*
- ³⁶ *Joint Institute for Nuclear Research, 141980 Dubna, Moscow region, Russia*
- ³⁷ *Justus-Liebig-Universitaet Giessen, II. Physikalisches Institut, Heinrich-Buff-Ring 16, D-35392 Giessen, Germany*
- ³⁸ *Lanzhou University, Lanzhou 730000, People's Republic of China*
- ³⁹ *Liaoning Normal University, Dalian 116029, People's Republic of China*
- ⁴⁰ *Liaoning University, Shenyang 110036, People's Republic of China*
- ⁴¹ *Nanjing Normal University, Nanjing 210023, People's Republic of China*
- ⁴² *Nanjing University, Nanjing 210093, People's Republic of China*
- ⁴³ *Nankai University, Tianjin 300071, People's Republic of China*
- ⁴⁴ *National Centre for Nuclear Research, Warsaw 02-093, Poland*
- ⁴⁵ *North China Electric Power University, Beijing 102206, People's Republic of China*
- ⁴⁶ *Peking University, Beijing 100871, People's Republic of China*
- ⁴⁷ *Qufu Normal University, Qufu 273165, People's Republic of China*
- ⁴⁸ *Renmin University of China, Beijing 100872, People's Republic of China*
- ⁴⁹ *Shandong Normal University, Jinan 250014, People's Republic of China*
- ⁵⁰ *Shandong University, Jinan 250100, People's Republic of China*
- ⁵¹ *Shanghai Jiao Tong University, Shanghai 200240, People's Republic of China*
- ⁵² *Shanxi Normal University, Linfen 041004, People's Republic of China*
- ⁵³ *Shanxi University, Taiyuan 030006, People's Republic of China*
- ⁵⁴ *Sichuan University, Chengdu 610064, People's Republic of China*
- ⁵⁵ *Soochow University, Suzhou 215006, People's Republic of China*
- ⁵⁶ *South China Normal University, Guangzhou 510006, People's Republic of China*
- ⁵⁷ *Southeast University, Nanjing 211100, People's Republic of China*
- ⁵⁸ *State Key Laboratory of Particle Detection and Electronics, Beijing 100049, Hefei 230026, People's Republic of China*
- ⁵⁹ *Sun Yat-Sen University, Guangzhou 510275, People's Republic of China*
- ⁶⁰ *Suranaree University of Technology, University Avenue 111, Nakhon Ratchasima 30000, Thailand*
- ⁶¹ *Tsinghua University, Beijing 100084, People's Republic of China*
- ⁶² *Turkish Accelerator Center Particle Factory Group, (A)Istinye University, 34010, Istanbul, Turkey; (B)Near East University, Nicosia, North Cyprus, 99138, Mersin 10, Turkey*
- ⁶³ *University of Bristol, H.H. Wills Physics Laboratory, Tyndall Avenue, Bristol, BS8 1TL, U.K.*
- ⁶⁴ *University of Chinese Academy of Sciences, Beijing 100049, People's Republic of China*
- ⁶⁵ *University of Groningen, NL-9747 AA Groningen, The Netherlands*
- ⁶⁶ *University of Hawaii, Honolulu, Hawaii 96822, U.S.A.*
- ⁶⁷ *University of Jinan, Jinan 250022, People's Republic of China*
- ⁶⁸ *University of Manchester, Oxford Road, Manchester, M13 9PL, United Kingdom*
- ⁶⁹ *University of Muenster, Wilhelm-Klemm-Strasse 9, 48149 Muenster, Germany*
- ⁷⁰ *University of Oxford, Keble Road, Oxford OX13RH, United Kingdom*
- ⁷¹ *University of Science and Technology Liaoning, Anshan 114051, People's Republic of China*
- ⁷² *University of Science and Technology of China, Hefei 230026, People's Republic of China*
- ⁷³ *University of South China, Hengyang 421001, People's Republic of China*
- ⁷⁴ *University of the Punjab, Lahore-54590, Pakistan*
- ⁷⁵ *University of Turin and INFN, (A)University of Turin, I-10125, Turin, Italy; (B)University of Eastern Piedmont, I-15121, Alessandria, Italy; (C)INFN, I-10125, Turin, Italy*
- ⁷⁶ *Uppsala University, Box 516, SE-75120 Uppsala, Sweden*
- ⁷⁷ *Wuhan University, Wuhan 430072, People's Republic of China*
- ⁷⁸ *Yantai University, Yantai 264005, People's Republic of China*
- ⁷⁹ *Yunnan University, Kunming 650500, People's Republic of China*
- ⁸⁰ *Zhejiang University, Hangzhou 310027, People's Republic of China*
- ⁸¹ *Zhengzhou University, Zhengzhou 450001, People's Republic of China*

^a *Deceased*

^b *Also at the Moscow Institute of Physics and Technology, Moscow 141700, Russia*

- ^c Also at the Novosibirsk State University, Novosibirsk, 630090, Russia
- ^d Also at the NRC “Kurchatov Institute”, PNPI, 188300, Gatchina, Russia
- ^e Also at Goethe University Frankfurt, 60323 Frankfurt am Main, Germany
- ^f Also at Key Laboratory for Particle Physics, Astrophysics and Cosmology, Ministry of Education; Shanghai Key Laboratory for Particle Physics and Cosmology; Institute of Nuclear and Particle Physics, Shanghai 200240, People’s Republic of China
- ^g Also at Key Laboratory of Nuclear Physics and Ion-beam Application (MOE) and Institute of Modern Physics, Fudan University, Shanghai 200443, People’s Republic of China
- ^h Also at State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, People’s Republic of China
- ⁱ Also at School of Physics and Electronics, Hunan University, Changsha 410082, China
- ^j Also at Guangdong Provincial Key Laboratory of Nuclear Science, Institute of Quantum Matter, South China Normal University, Guangzhou 510006, China
- ^k Also at MOE Frontiers Science Center for Rare Isotopes, Lanzhou University, Lanzhou 730000, People’s Republic of China
- ^l Also at Lanzhou Center for Theoretical Physics, Lanzhou University, Lanzhou 730000, People’s Republic of China
- ^m Also at the Department of Mathematical Sciences, IBA, Karachi 75270, Pakistan
- ⁿ Also at Ecole Polytechnique Federale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland
- ^o Also at Helmholtz Institute Mainz, Staudinger Weg 18, D-55099 Mainz, Germany
- ^p Also at Hangzhou Institute for Advanced Study, University of Chinese Academy of Sciences, Hangzhou 310024, China