

Measurement of the Born cross section for $e^+e^- \rightarrow K_S^0 \Xi^+ \Sigma^-$ at $\sqrt{s} = 3.51\text{--}4.95$ GeV

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(Received 26 July 2026; accepted 25 August 2026; published 11 September 2026)

Using e^+e^- collision data collected with the BESIII detector at the BEPCII collider corresponding to a total integrated luminosity of 44 fb^{-1} , we present the first measurement of the Born cross sections for the process $e^+e^- \rightarrow K_S^0 \Xi^+ \Sigma^-$ at 56 center-of-mass energies from 3.510 to 4.951 GeV. By fitting the dressed cross sections of $e^+e^- \rightarrow K_S^0 \Xi^+ \Sigma^-$ with the assumption of a power-law function plus a charmonium(-like) resonance, i.e., $\psi(3770)$, $\psi(4040)$, $\psi(4160)$, $Y(4230)$, $Y(4360)$, $\psi(4415)$, $Y(4500)$, $Y(4660)$, and $Y(4710)$, no significant signal of any charmonium(-like) state decaying into the $K_S^0 \Xi^+ \Sigma^-$ is observed. Upper limits on the product of the electronic width and branching fraction at the 90% confidence level are given for each resonance. Combining this result with the previous measurement of the isospin-symmetric process $e^+e^- \rightarrow K^- \Xi^+ \Sigma^0$, the ratio of the Born cross sections, $R = \sigma^B(e^+e^- \rightarrow K_S^0 \Xi^+ \Sigma^-) / \sigma^B(e^+e^- \rightarrow K^- \Xi^+ \Sigma^0)$, is found to be consistent with unity.

DOI: [10.1103/pwj2-q35c](https://doi.org/10.1103/pwj2-q35c)

Studies of baryonic final states in e^+e^- annihilation provide essential input for understanding the production mechanisms of charmonium(-like) states. In particular, investigating the production of charmonium(-like) states above the open-charm threshold and their hadronic decays offers a sensitive test of QCD calculations and a unique probe of XYZ states [1–4]. Potential models predict five vector charmonium states between 3.773 and 4.7 GeV/ c^2 : the $3S$, $2D$, $4S$, $3D$, and $5S$ states [1]. However, experiments have observed more vector states in this region than predicted. Several states, such as the $\psi(4040)$, $\psi(4160)$, and $\psi(4415)$, are seen in hadronic cross sections [5]. In addition, via initial-state radiation (ISR), the BABAR and Belle collaborations have observed three charmonium-like states: $Y(4230)$, $Y(4360)$, and $Y(4660)$ [6–14]. Direct production at the CLEO [15] and BESIII [16,17] experiments has confirmed the $Y(4230)$, $Y(4360)$, and $Y(4660)$ states; these cannot be classified within the simple $c\bar{c}$ quark model, and their nature remains unresolved. Refs. [18,19] suggest that these states be considered pure charmonium states, provided that their baryonic decays can be observed. This situation highlights the incomplete understanding of the strong interaction, particularly in its nonperturbative aspects. Although BESIII has performed extensive studies

in this energy region [20–38], only $\psi(3770) \rightarrow \Lambda \bar{\Lambda}$ [25] and $\psi(3770) \rightarrow \Xi^- \bar{\Xi}^+$ [26] have been reported. To clarify the nature of these charmonium(-like) states, precise measurements of exclusive $e^+e^- \rightarrow$ baryonic cross sections above the open-charm threshold are essential.

This Letter reports the first measurement of the Born cross sections for $e^+e^- \rightarrow K_S^0 \Xi^+ \Sigma^-$ (hereafter, the charge-conjugate model is implied by default). The ratio of the Born cross sections to those for $e^+e^- \rightarrow K^- \Xi^+ \Sigma^0$ is also determined. The data correspond to an integrated luminosity of 44 fb^{-1} of e^+e^- collisions at center-of-mass (c.m.) energies $\sqrt{s}$ between 3.510 and 4.951 GeV [39–44], collected by the BESIII detector [45] at the BEPCII collider [46].

Event candidates for $e^+e^- \rightarrow K_S^0 \Xi^+ \Sigma^-$ are selected via a partial-reconstruction technique. Only K_S^0 and Ξ^+ are reconstructed, through the decays $K_S^0 \rightarrow \pi^+ \pi^-$ and $\Xi^+ \rightarrow \bar{\Lambda} \pi^+$ with $\bar{\Lambda} \rightarrow \bar{p} \pi^+$; the Σ^- is inferred from the recoil against the reconstructed $K_S^0 \Xi^+$ system. Monte Carlo (MC) samples are produced with a Geant4-based [47] package that includes the BESIII geometry and a realistic detector response; these are used to determine efficiencies and estimate background contributions. Detection efficiencies for $e^+e^- \rightarrow K_S^0 \Xi^+ \Sigma^-$ are obtained from 4×10^5 phase-space (PHSP) events generated at each energy point with the KKMC generator [48,49], which incorporates beam-energy spread and ISR corrections. Subsequent decays are simulated with EvtGen [50,51] using branching fractions from the Particle Data Group (PDG) [5]; unmeasured modes are handled by LUNDCHARM [52]. An inclusive MC sample generated at $\sqrt{s} = 3.773$ GeV is used to

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estimate backgrounds; it includes $D\bar{D}$ production (with quantum coherence for neutral D mesons), non- $D\bar{D}$ decays of $\psi(3770)$, ISR production of J/ψ and $\psi(3686)$, and continuum processes incorporated in KKMC [48,49].

Charged tracks are reconstructed in the multilayer drift chamber (MDC) within the angular region $|\cos\theta| < 0.93$, where θ is the polar angle with respect to the symmetry axis of the MDC. At least three positive-charged tracks and two negative-charged tracks are required to be reconstructed in the MDC. Particle identification (PID) for charged tracks combines measurements of the specific ionization energy loss in the MDC (dE/dx) and the flight time in the time-of-flight system 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 $\mathcal{L}(p) > \mathcal{L}(\pi)$), and as pions when $\mathcal{L}(\pi) > \mathcal{L}(p)$ and $\mathcal{L}(\pi) > \mathcal{L}(K)$. Events with at least one $\bar{p}$, three π^+ s, and one π^- are kept for further analyses.

To reconstruct the K_S^0 candidate, a vertex fit and secondary vertex fit are applied to all $\pi^+\pi^-$ combinations with a mass difference minimization strategy, $\delta_{K_S^0} = |M_{\pi^+\pi^-} - m_{K_S^0}|$, which reconstructs the displaced decay vertex and provides the decay length used in the subsequent selection. Here, $M_{\pi^+\pi^-}$ denoted the invariant mass of the $\pi^+\pi^-$ combination, and $m_{K_S^0}$ is the nominal K_S^0 mass taken from the PDG [5]. To suppress the potential background candidates, the $\pi^+\pi^-$ invariant mass is required to be within 12 MeV/ c^2 of the nominal K_S^0 mass, and the K_S^0 decay length over its uncertainty is required to be $L_{K_S^0}/\Delta L_{K_S^0} > 2$ [53]. To reconstruct the $\bar{\Lambda}$ candidates, a similar secondary vertex fit is applied to all $\bar{p}\pi^+$ combinations. The invariant mass of $\bar{p}\pi^+$ is required to be $|M_{\bar{p}\pi^+} - m_{\bar{\Lambda}}| < 5$ MeV/ c^2 [25], and the decay length of $\bar{\Lambda}$ is required to be larger than zero [28]. Here, $M_{\bar{p}\pi^+}$ denoted the invariant mass of the $\bar{p}\pi^+$ combination, and $m_{\bar{\Lambda}}$ is the nominal $\bar{\Lambda}$ mass taken from the PDG [5].

The Ξ^+ candidates are formed by combining an additional π^+ with a reconstructed $\bar{\Lambda}$ and performing a secondary-vertex fit. The $\bar{\Lambda}\pi^+$ invariant mass must satisfy $|M_{\bar{\Lambda}\pi^+} - m_{\Xi^+}| < 8$ MeV/ c^2 , and the decay length is required to be positive. The best $\bar{\Lambda}$ and Ξ^+ candidates are selected by minimizing $\delta_{\min} = \sqrt{|M_{\bar{p}\pi^+} - m_{\bar{\Lambda}}|^2 + |M_{\bar{\Lambda}\pi^+} - m_{\Xi^+}|^2}$. Here, $M_{\bar{\Lambda}\pi^+}$ denoted the invariant mass of the $\bar{\Lambda}\pi^+$ combination, and m_{Ξ^+} is the nominal Ξ^+ mass taken from the PDG [5]. The Σ^- is inferred from the recoil mass against the $K_S^0\Xi^+$ system:

$$M_{K_S^0\Xi^+}^{\text{recoil}} = \sqrt{(\sqrt{s} - E_{K_S^0\Xi^+})^2 - |\vec{p}_{K_S^0\Xi^+}|^2}, \quad (1)$$

where $E_{K_S^0\Xi^+}$ and $\vec{p}_{K_S^0\Xi^+}$ are the energy and momentum of the selected $K_S^0\Xi^+$ system in the e^+e^- c.m. frame,

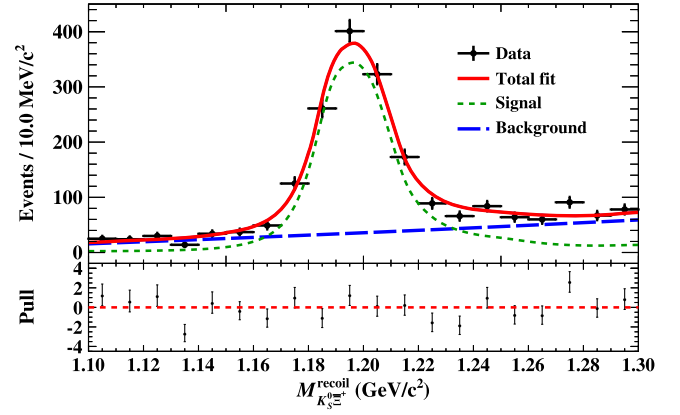


FIG. 1. Fit to $M_{K_S^0\Xi^+}^{\text{recoil}}$ at $\sqrt{s} = 3.773$ GeV. Black dots with error bars are data; the red solid line is the total fit; the green short-dashed line is the signal; the blue long-dashed line is the background. The bottom panel shows the pull distribution.

respectively. After applying all selection criteria to the inclusive MC sample at $\sqrt{s} = 3.686$ and $\sqrt{s} = 3.773$ GeV, the remaining background contribution in the signal region is found to be smoothly distributed.

The signal yield for $e^+e^- \rightarrow K_S^0\Xi^+\Sigma^-$ at each energy point is extracted with an extended maximum-likelihood fit to the $M_{K_S^0\Xi^+}^{\text{recoil}}$ distribution in the range from 1.1 to 1.3 GeV/ c^2 . In the fit, the signal shape is described by the MC-simulated shape convolved with a Gaussian function that accounts for the difference of mass resolution between data and MC events; for energy points with fewer than 20 events, the pure MC shape is used. Backgrounds are described by first- or second-order polynomials. Figure 1 demonstrates the fit to the $M_{K_S^0\Xi^+}^{\text{recoil}}$ distribution at $\sqrt{s} = 3.773$ GeV.

The Born cross section (σ^B) for $e^+e^- \rightarrow K_S^0\Xi^+\Sigma^-$ at a given c.m. energy is calculated as

$$\sigma^B = \frac{N_{\text{obs}}}{\mathcal{L} \cdot (1 + \delta) \cdot \frac{1}{|1 - \Pi|^2} \cdot \epsilon \cdot \mathcal{B}}, \quad (2)$$

where N_{obs} is the signal yield, $\mathcal{L}$ is the integrated luminosity, $(1 + \delta)$ is the ISR correction, $1/|1 - \Pi|^2$ is the vacuum-polarization (VP) correction, ϵ is the detection efficiency, and $\mathcal{B}$ is the product of the branching fractions for $K_S^0 \rightarrow \pi^+\pi^-$, $\Xi^+ \rightarrow \bar{\Lambda}\pi^+$, and $\bar{\Lambda} \rightarrow \bar{p}\pi^+$ taken from the PDG [5]. The ISR correction is obtained from QED calculations [54], and the VP correction is computed with a VP computation package [55]. Efficiencies and ISR factors are determined iteratively as proposed in Ref. [54]. Numerical results for each energy are collected in Table II in Appendix. Figure 2 shows the Born cross section for the reaction of $e^+e^- \rightarrow K_S^0\Xi^+\Sigma^-$ compared with that of $e^+e^- \rightarrow K^-\Xi^+\Sigma^0$ [29], along with their ratio.

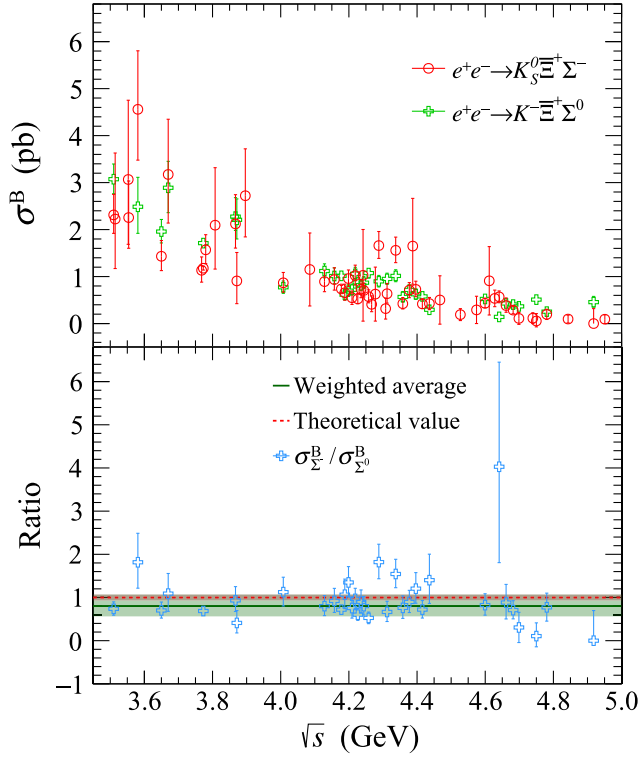


FIG. 2. *Top*: Comparison of the Born cross sections between this work and the previous measurement for the reaction of $e^+e^- \rightarrow K^-\Xi^+\Sigma^0$ [29] as a function of c.m. energy at $\sqrt{s} = 3.510\text{--}4.951$ GeV. *Bottom*: Ratio of the Born cross sections for both reactions. The red dashed line with error bars stands for the theoretical calculated value; the solid green line with error bars represents the weighted average value of the measurement.

Systematic uncertainties in the cross-section measurement arise from the integrated luminosity K_S^0 and Ξ^+ reconstruction, intermediate-state branching fractions, the physical model, signal and background shapes, and the input lineshape. The luminosity at all energy points is evaluated using the Bhabha scattering process with an uncertainty of about 1.0% [40] below 4.0 GeV, 0.7% [41] from 4.0 to 4.6 GeV, and 0.6% [42] above 4.6 GeV. Reconstruction uncertainties for K_S^0 and Ξ^+ (tracking, PID, mass windows, and decay-length requirements) are evaluated using control samples of $J/\psi \rightarrow K^{*\pm}(892)K^\mp$, $K^{*\pm}(892) \rightarrow K_S^0\pi^\pm$, and $\psi(3686) \rightarrow \Xi^-\Xi^+$, yielding 2.1% and 4.4%, respectively [56–58]. The uncertainty due to the branching fractions of the intermediate states is taken from the PDG [5]. The decays of $K_S^0 \rightarrow \pi^+\pi^-$, $\Xi^+ \rightarrow \bar{\Lambda}\pi^+$, and $\bar{\Lambda} \rightarrow \bar{p}\pi^+$, which contribute as 0.8%. The model dependence is assessed by comparing efficiencies obtained from the PHSP generator with those from a partial-wave analysis of $e^+e^- \rightarrow K_S^0\Xi^+\Sigma^-$ at $\sqrt{s} = 3.773$ GeV [59,60], and the 2.5% difference is taken as the systematic uncertainty. The uncertainty of the signal shape for the fit of $M_{K_S^0\Xi^+}^{\text{recoil}}$ is evaluated by combining all

energy points and varying the Gaussian parameters within the range of 1σ , and the difference in the signal yield, 1.3%, is taken as the systematic uncertainty. The uncertainty due to the background shape is estimated through an alternative fit with a higher-order polynomial function. The polynomial order is increased from 1st to 2nd or from 2nd to 3rd. The resulting difference of 1.7% and 0.1% between the nominal and higher-order fits are taken as the systematic uncertainty. The uncertainty for input lineshape of cross section has two components: the parameterization and the model. The former is treated as in Refs. [31,54]; the latter is estimated by replacing the nominal power-law function with a sum of $\psi(3770)$ Breit-Wigner and power-law functions, recalculating $\varepsilon \cdot (1 + \delta)$, and taking the largest deviation (0.6%). All individual contributions are added in quadrature to obtain the total systematic uncertainty.

Resonances or charmonium(-like) states produced in $e^+e^- \rightarrow K_S^0\Xi^+\Sigma^-$ are searched for by fitting the dressed cross sections $\sigma^d = \sigma^B/|1 - \Pi|^2$ (including VP) with the least-squares method [61–63]. Systematic uncertainties on luminosity, K_S^0 , Ξ^+ reconstruction, branching fractions, MC model, and the input lineshape are treated as correlated; those on the fit range, background and signal shapes, and the statistical uncertainties are uncorrelated. Assuming a sum of resonance as continuum, the dressed cross sections are fitted to the coherent sum of a power-law and a Breit-Wigner (BW) function:

$$\sigma^d(\sqrt{s}) = \left| c_0 \frac{\sqrt{P(\sqrt{s})}}{(\sqrt{s})^n} + e^{i\Phi} BW(\sqrt{s}) \sqrt{\frac{P(\sqrt{s})}{P(M)}} \right|^2, \quad (3)$$

where Φ is the relative phase,

$$BW(\sqrt{s}) = \frac{\sqrt{12\pi}\Gamma_{ee}\mathcal{B}\Gamma}{s - M^2 + iM\Gamma}. \quad (4)$$

$\sqrt{P(\sqrt{s})}$ is the three-body PHSP factor, M and Γ are the mass and width of the assumed resonance, i.e., $\psi(3770)$, $\psi(4040)$, $\psi(4160)$, $Y(4230)$, $Y(4360)$, $\psi(4415)$, $Y(4500)$ [64], $Y(4660)$, or $Y(4710)$ [65], which are fixed to the PDG values [5], the parameters n and c_0 are left free in the fit, and $\Gamma_{ee}\mathcal{B}$ is the product of the electronic partial width and the branching fraction for the assumed resonance decaying into the $K_S^0\Xi^+\Sigma^-$ final state. No significant signal is found, and the upper limits of the $\Gamma_{ee}\mathcal{B}$ for these charmonium (-like) states decaying into the $K_S^0\Xi^+\Sigma^-$ final state are provided at the 90% confidence level (C.L.) using a Bayesian approach [66]. Figure 3 shows the fit to the dressed cross sections and the scan for multiple solutions of the $\psi(3770)$. The resonance parameters from the fit of different resonances one at a time are summarized in Table I. More details can be found in Table III in Appendix. More details can be found in Appendix. Figure 2 shows the Born cross sections for the processes

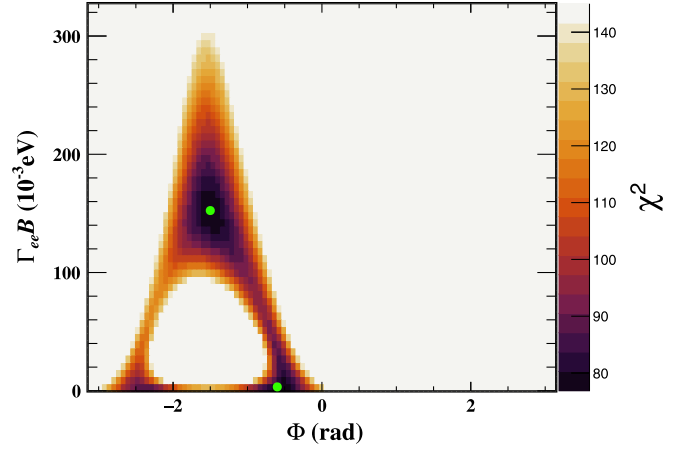
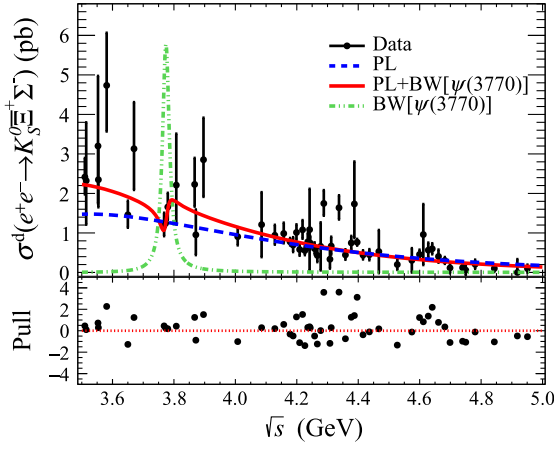


FIG. 3. *Left*: Fit to the dressed cross sections of $e^+e^- \rightarrow K_S^0 \Xi^+ \Sigma^-$. Dots with error bars are the measured dressed cross sections (statistical and systematic uncertainties combined). The blue dashed line is the power-law contribution; the green dashed line is the $\psi(3770)$ signal; the red solid line is the total fit. The bottom panel shows the pull distribution. *Right*: Contours of $\Gamma_{ee} \mathcal{B}$ versus Φ for $\psi(3770)$. Green markers indicate the best-fit points.

$e^+e^- \rightarrow K_S^0 \Xi^+ \Sigma^-$ and $e^+e^- \rightarrow K^- \Xi^+ \Sigma^0$ [29], as well as their ratio.

Furthermore, the ratio of the Born cross sections is used to test isospin conservation. Based on the assumption of isospin conservation and quark flavor compositions of Σ and Ξ baryons, the ratio of the Born cross sections for the

processes $e^+e^- \rightarrow \bar{K}^0 \Xi^+ \Sigma^-$ and $e^+e^- \rightarrow K^- \Xi^+ \Sigma^0$ is predicted to be $R_{\bar{K}^0/K^-} = 2$. However, only the mass eigenstate K_S^0 , associated with the $\pi\pi$ final state, can be reconstructed experimentally. Given that the branching fraction for $K_S^0 \rightarrow \pi\pi$ is close to 1 [5], we obtain the relation $K_S^0 \approx K_{CP=1}$. Neutral kaons undergo $\bar{K}^0 - K^0$ oscillation via the weak interaction, and the CP eigenstates of the neutral K mesons are defined as

$$\begin{aligned} K_{CP=1} &= \frac{1}{\sqrt{2}}(|K^0\rangle + |\bar{K}^0\rangle), \\ K_{CP=-1} &= \frac{1}{\sqrt{2}}(|K^0\rangle - |\bar{K}^0\rangle). \end{aligned} \quad (5)$$

TABLE I. Fitted resonance parameters for $\Gamma_{ee} \mathcal{B}$ (10^{-3} eV) and ϕ (rad) for the two solutions (I, II). Statistical and systematic uncertainties are included. Bracketed values are conservative 90% C.L. upper limits obtained from $\Delta\chi^2$ scans. The number of degrees of freedom is 51, and $\chi^2/n.d.f$ for the continuum-only fit is 1.7.

Resonance	Φ (rad)	$\Gamma_{ee} \mathcal{B}$ ($\times 10^{-3}$ eV)	$\chi^2/n.d.f$
$\psi(3770)^I$	-0.6 ± 0.1	$6.6^{+4.8}_{-3.2}$	1.3
$\psi(3770)^{II}$	-1.4 ± 0.1	$159.6^{+8.8}_{-8.4}$ (< 173.0)	1.3
$\psi(4040)^I$	0.7 ± 0.9	$1.2^{+3.2}_{-1.2}$	1.5
$\psi(4040)^{II}$	-1.6 ± 0.1	$375.3^{+43.9}_{-44.8}$ (< 473.0)	1.5
$\psi(4160)^I$	1.1 ± 0.9	$0.0^{+0.0}_{-0.0}$	1.6
$\psi(4160)^{II}$	-1.6 ± 0.3	$249.6^{+13.7}_{-12.8}$ (< 275.0)	1.6
$Y(4230)^I$	-1.3 ± 2.0	$0.0^{+0.0}_{-0.0}$	1.6
$Y(4230)^{II}$	-1.6 ± 0.2	$164.5^{+9.9}_{-9.4}$ (< 188.0)	1.6
$Y(4360)^I$	1.8 ± 0.2	$4.5^{+2.3}_{-1.8}$	1.5
$Y(4360)^{II}$	-1.7 ± 0.1	$372.0^{+20.7}_{-19.4}$ (< 412.0)	1.5
$\psi(4415)^I$	2.7 ± 0.3	$4.5^{+2.5}_{-1.8}$	1.5
$\psi(4415)^{II}$	-1.8 ± 0.1	$301.5^{+19.8}_{-19.0}$ (< 350.0)	1.5
$Y(4500)^I$	-3.1 ± 0.7	$3.6^{+2.4}_{-1.7}$	1.5
$Y(4500)^{II}$	-1.7 ± 0.1	$265.5^{+29.0}_{-29.7}$ (< 332.0)	1.5
$Y(4660)^I$	2.3 ± 0.3	$3.7^{+2.3}_{-1.8}$	1.4
$Y(4660)^{II}$	-1.7 ± 0.1	$169.8^{+12.4}_{-12.1}$ (< 198.0)	1.4
$Y(4710)^I$	-2.4 ± 0.2	$21.3^{+15.6}_{-9.0}$	1.5
$Y(4710)^{II}$	-1.9 ± 0.1	$157.5^{+26.3}_{-31.3}$ (< 216.0)	1.5

The squared probability amplitude for finding K_S^0 in the $\bar{K}^0$ state is given by $P = \langle K_S^0 | \bar{K}^0 \rangle^2 \approx |1/\sqrt{2}|^2 = 1/2$. Hence, the ratio of the Born cross sections for $e^+e^- \rightarrow K_S^0 \Xi^+ \Sigma^-$ and $e^+e^- \rightarrow K^- \Xi^+ \Sigma^0$ is found to be $R_{K_S^0/K^-} = R_{\bar{K}^0/K^-} \cdot P \approx 1$. The weighted average of the ratio in Fig. 2 is 0.8 ± 0.2 , where the uncertainty includes both statistical and systematic contributions. This result is consistent with the isospin conservation assumption.

In summary, using a total of 44 fb $^{-1}$ of e^+e^- collision data collected by the BESIII detector at the BEPCII collider, we present the first measurement of the Born cross sections for the $e^+e^- \rightarrow K_S^0 \Xi^+ \Sigma^-$ reaction at 56 c.m. energies between 3.510 and 4.951 GeV. A fit to the dressed cross sections of $e^+e^- \rightarrow K_S^0 \Xi^+ \Sigma^-$ is performed assuming individual charmonium(-like) resonances [*i.e.*, $\psi(3770)$, $\psi(4040)$, $\psi(4160)$, $Y(4230)$, $Y(4360)$, $\psi(4415)$, $Y(4500)$, $Y(4660)$, and $Y(4710)$] and a continuum contribution. No evidence for any possible charmonium(-like) states is found. Upper limits for the products of the branching fraction and the electronic partial width at the 90% C.L. are

provided. Based on the Ref. [29] results, we determine the average ratio of cross sections for two processes to be $R = \frac{\sigma^B(e^+e^- \rightarrow K_S^0 \Xi^+ \Sigma^-)}{\sigma^B(e^+e^- \rightarrow K^- \Xi^+ \Sigma^0)} = 0.8 \pm 0.2$. This measured ratio is consistent with expectations from isospin conservation and $K^0 - \bar{K}^0$ oscillation. These results offer new experimental insight into three-body baryon production above the open-charm threshold and into the nature of charmonium(-like) states [18,19,70].

Acknowledgments. The BESIII Collaboration thanks the staff of BEPCII [71] 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 No. 2023YFA1606000, No. 2023YFA1606704; National Natural Science Foundation of China (NSFC) under Contracts No. 12247101, No. 11635010, No. 11935015, No. 11935016, No. 11935018, No. 12025502, No. 12035009, No. 12035013, No. 12061131003, No. 12192260, No. 12192261, No. 12192262, No. 12192263, No. 12192264, No. 12192265, No. 12221005, No. 12225509, No. 12235017, No. 12342502, and No. 12361141819; the Fundamental Research Funds for the Central Universities No. lzujbky-2025-ytA05, No. lzujbky-2025-it06, No. lzujbky-2024-jdxx06; the Natural Science Foundation of Gansu Province No. 22JR5RA389, No. 25JRRA799; the “111 Center” under Grant No. B20063; the Chinese Academy of Sciences (CAS) Large-Scale Scientific Facility Program;

the Strategic Priority Research Program of Chinese Academy of Sciences under Contract No. XDA0480600; CAS under Contract No. YSBR-101; 100 Talents Program of CAS; The Institute of Nuclear and Particle Physics (INPAC) and Shanghai Key Laboratory for Particle Physics and Cosmology; ERC under Contract No. 758462; German Research Foundation DFG under Contract No. FOR5327; Istituto Nazionale di Fisica Nucleare, Italy; Knut and Alice Wallenberg Foundation under Contract No. 2021.0174, No. 2021.0299, No. 2023.0315; 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; Polish National Science Centre under Contract No. 2024/53/B/ST2/00975; STFC (United Kingdom); Swedish Research Council under Contract No. 2019.04595; U.S. Department of Energy under Contract No. DE-FG02-05ER41374.

Data availability. There are no publicly available research data or software supporting this manuscript. Requests for further information or data should be sent to the authors.

APPENDIX

This End Matter provides detailed information on the measured Born cross sections for the process $e^+e^- \rightarrow K_S^0 \Xi^+ \Sigma^-$.

TABLE II. The $e^+e^- \rightarrow K_S^0 \Xi^+ \Sigma^-$ Born cross sections σ^B for 56 energy points between 3.510 and 4.951 GeV. The values in the brackets are the corresponding upper limits at the 90% C.L.. The first uncertainties are statistical, and the second systematic. The $\sqrt{s}$ is the e^+e^- c.m. energy [67,68], $\int \mathcal{L} dt$ is the integrated luminosity of each data set [39–44,69], the vacuum polarization correction factor $\frac{1}{|1-\Pi|^2}$, the detection efficiency ϵ , and the ISR correction factor $(1 + \delta)$. N_{obs} is the signal yield (the upper limits of signal yields including additive part of systematic uncertainty at the 90% C.L. at these energy points are determined with the Bayesian method [66]). S is the statistical significance.

$\sqrt{s}$ (GeV)	$\int \mathcal{L} dt$ (pb ⁻¹)	$\frac{1}{ 1-\Pi ^2}$	$(1 + \delta)$	ϵ (%)	N_{obs} (N^{UL})	σ^B (fb)	S (σ)
3.510	405.7	1.0444	0.7105	12.03	$37.1^{+7.0}_{-6.3}$	$2312^{+436}_{-393} \pm 135$	5.6
3.514	40.9	1.0441	0.7331	12.32	$3.8^{+2.4}_{-1.8} (< 30.0)$	$2322^{+1475}_{-1111} \pm 152 (< 17561)$	1.1
3.552	42.2	1.0436	0.8166	12.29	$6.0^{+3.3}_{-2.7} (< 21.8)$	$3200^{+1773}_{-1455} \pm 210 (< 11142)$	0.9
3.554	129.4	1.0406	0.8171	13.19	$14.5^{+5.0}_{-4.2} (< 41.1)$	$2347^{+824}_{-697} \pm 154 (< 6370)$	2.3
3.581	85.7	1.0385	0.8465	12.75	$19.4^{+5.3}_{-4.6}$	$4559^{+1245}_{-1081} \pm 277$	3.3
3.650	454.5	1.0190	0.8988	13.76	$37.1^{+8.7}_{-7.9}$	$1432^{+336}_{-305} \pm 87$	4.1
3.670	84.7	0.9868	0.9105	12.62	$13.5^{+5.0}_{-4.4} (< 29.7)$	$3173^{+1175}_{-1034} \pm 192 (< 6980)$	1.8
3.768	415.8	1.0548	0.9618	13.14	$27.9^{+7.0}_{-6.2} (< 38.9)$	$1136^{+285}_{-252} \pm 69 (< 1580)$	2.4
3.773	20249.8	1.0570	0.9624	13.42	$1413.7^{+48.6}_{-47.8}$	$1154^{+40}_{-39} \pm 67$	$\gg 5$
3.780	410	1.0598	0.9657	13.24	$38.5^{+7.9}_{-7.2}$	$1563^{+321}_{-292} \pm 91$	4.4
3.808	50.5	1.0561	0.9778	13.43	$6.5^{+3.8}_{-2.9} (< 21.1)$	$2093^{+1224}_{-934} \pm 127 (< 6795)$	1.9
3.867	108.9	1.0507	1.0032	12.98	$14.0^{+4.1}_{-3.4}$	$2121^{+621}_{-515} \pm 129$	4.0
3.871	110.3	1.0504	1.0053	12.81	$6.0^{+4.0}_{-3.2} (< 22.0)$	$907^{+605}_{-484} \pm 55 (< 3327)$	1.5
3.896	52.6	1.0486	1.0154	13.33	$9.0^{+3.3}_{-2.9} (< 23.8)$	$2720^{+997}_{-877} \pm 165 (< 7194)$	2.7

(Table continued)

TABLE II. (*Continued*)

$\sqrt{s}$ (GeV)	$\int \mathcal{L} dt$ (pb $^{-1}$)	$\frac{1}{ 1-\Pi ^2}$	$(1 + \delta)$	ϵ (%)	$N_{\text{obs}} (N^{\text{UL}})$	σ^B (fb)	S (σ)
4.008	482	1.0438	1.0651	13.21	$27.2^{+6.9}_{-6.3}$	$867^{+220}_{-201} \pm 52$	3.8
4.085	52.9	1.0515	1.0966	12.86	$4.0^{+2.7}_{-2.7} (< 8.4)$	$1151^{+777}_{-777} \pm 67 (< 2416)$	1.8
4.128	401.5	1.0526	1.1178	11.77	$22.0^{+6.0}_{-5.3}$	$893^{+244}_{-215} \pm 54$	3.5
4.157	408.7	1.0535	1.1332	11.77	$23.8^{+6.4}_{-5.7} (< 47.8)$	$936^{+252}_{-224} \pm 56 (< 1879)$	2.9
4.178	3189	1.0543	1.1415	12.11	$151.7^{+15.5}_{-14.7}$	$737^{+75}_{-71} \pm 43$	8.7
4.188	526.7	1.0559	1.1465	12.20	$22.6^{+6.3}_{-5.5}$	$656^{+183}_{-160} \pm 40$	3.0
4.199	526	1.0567	1.1516	12.37	$33.6^{+6.4}_{-5.8}$	$958^{+182}_{-165} \pm 58$	4.2
4.209	517.1	1.0565	1.1576	11.95	$18.4^{+4.8}_{-4.8} (< 35.8)$	$550^{+143}_{-143} \pm 33 (< 1069)$	2.3
4.219	514.6	1.0564	1.1609	11.91	$34.0^{+7.4}_{-6.7}$	$1021^{+222}_{-201} \pm 59$	4.1
4.226	1100.9	1.0562	1.1643	12.69	$40.0^{+8.6}_{-7.9}$	$525^{+113}_{-104} \pm 32$	3.7
4.236	530.3	1.0554	1.1703	12.35	$26.3^{+7.3}_{-6.6}$	$734^{+204}_{-184} \pm 44$	3.0
4.242	55.88	1.0555	1.1742	12.70	$4.0^{+3.8}_{-3.8} (< 8.4)$	$1026^{+975}_{-975} \pm 62 (< 2156)$	2.2
4.244	538.1	1.0555	1.1743	12.20	$25.4^{+5.7}_{-5.0}$	$704^{+158}_{-139} \pm 41$	3.3
4.258	828.4	1.0535	1.1818	12.49	$32.7^{+8.2}_{-7.5} (< 55.3)$	$573^{+144}_{-131} \pm 33 (< 969)$	2.8
4.267	531.1	1.0532	1.1867	12.13	$14.6^{+6.4}_{-5.6} (< 30.7)$	$409^{+179}_{-157} \pm 25 (< 861)$	1.2
4.278	175.7	1.0530	1.1920	11.76	$7.2^{+6.6}_{-6.6} (< 12.5)$	$627^{+574}_{-574} \pm 38 (< 1088)$	2.0
4.288	502.4	1.0526	1.1981	11.08	$51.6^{+9.3}_{-8.5}$	$1659^{+299}_{-273} \pm 100$	4.5
4.308	45.08	1.0523	1.2066	12.40	$1.0^{+0.7}_{-0.7} (< 3.7)$	$318^{+223}_{-223} \pm 19 (< 1177)$	0.8
4.312	501.2	1.0521	1.2102	11.14	$20.0^{+6.9}_{-6.3} (< 38.8)$	$635^{+219}_{-200} \pm 38 (< 1232)$	1.7
4.337	505.0	1.0508	1.2238	11.26	$50.5^{+9.1}_{-8.5}$	$1558^{+281}_{-262} \pm 94$	4.7
4.358	543.9	1.0511	1.2335	12.27	$16.2^{+5.0}_{-4.3} (< 22.3)$	$423^{+130}_{-112} \pm 24 (< 582)$	2.3
4.377	522.7	1.0514	1.2459	11.08	$23.9^{+5.4}_{-5.4}$	$711^{+161}_{-161} \pm 41$	3.2
4.387	55.6	1.0513	1.2517	12.16	$6.5^{+4.0}_{-3.2} (< 9.4)$	$1649^{+1015}_{-812} \pm 99 (< 2385)$	1.6
4.396	507.8	1.0513	1.2582	11.00	$23.7^{+5.7}_{-5.1}$	$724^{+174}_{-156} \pm 42$	3.6
4.416	1090.7	1.0524	1.2684	11.90	$32.1^{+8.4}_{-7.6} (< 49.2)$	$418^{+109}_{-99} \pm 25 (< 641)$	2.7
4.436	569.9	1.0541	1.2803	10.89	$15.8^{+4.8}_{-4.8} (< 32.9)$	$426^{+129}_{-129} \pm 25 (< 887)$	2.7
4.467	111.1	1.0548	1.3008	11.51	$3.9^{+4.0}_{-4.0} (< 6.1)$	$502^{+515}_{-515} \pm 30 (< 785)$	1.3
4.527	112.1	1.0545	1.3402	11.23	$1.5^{+1.0}_{-1.0} (< 3.7)$	$190^{+127}_{-127} \pm 11 (< 469)$	0.3
4.575	48.9	1.0545	1.3762	10.94	$1.0^{+1.0}_{-1.0} (< 3.7)$	$290^{+290}_{-290} \pm 17 (< 1075)$	1.1
4.600	586.9	1.0547	1.3928	10.93	$18.0^{+4.6}_{-4.0}$	$431^{+110}_{-96} \pm 26$	3.4
4.612	103.7	1.0545	1.4011	9.72	$6.0^{+4.8}_{-4.8} (< 11.2)$	$910^{+728}_{-728} \pm 55 (< 1698)$	2.2
4.628	521.5	1.0544	1.4125	9.39	$17.3^{+5.7}_{-5.7} (< 34.5)$	$535^{+176}_{-176} \pm 32 (< 1067)$	2.6
4.641	551.7	1.0544	1.4231	9.55	$19.9^{+4.4}_{-4.4}$	$568^{+126}_{-126} \pm 34$	3.3
4.661	529.4	1.0544	1.4424	9.35	$12.8^{+5.4}_{-4.8} (< 29.1)$	$384^{+162}_{-144} \pm 23 (< 872)$	1.6
4.682	1667.4	1.0545	1.4558	9.31	$30.2^{+8.5}_{-8.0} (< 31.7)$	$286^{+80}_{-76} \pm 17 (< 300)$	2.1
4.699	535.5	1.0545	1.4694	9.21	$3.7^{+4.3}_{-4.3} (< 6.1)$	$109^{+127}_{-127} \pm 6 (< 180)$	0.5
4.740	163.9	1.0548	1.5008	9.85	$1.3^{+1.3}_{-1.3} (< 4.2)$	$115^{+115}_{-115} \pm 7 (< 371)$	0.6
4.750	366.6	1.0549	1.5098	9.87	$1.4^{+4.0}_{-3.2} (< 29.8)$	$55^{+157}_{-125} \pm 3 (< 1168)$	0.3
4.781	511.5	1.0552	1.5365	9.74	$7.0^{+3.9}_{-3.9} (< 14.9)$	$196^{+109}_{-109} \pm 12 (< 416)$	1.8
4.843	525.16	1.0557	1.6012	9.27	$3.5^{+3.0}_{-3.0} (< 6.1)$	$96^{+82}_{-82} \pm 6 (< 167)$	0.9
4.918	207.82	1.0562	1.6742	8.88	$0.0^{+4.6}_{-0.0} (< 7.7)$	$0^{+318}_{-0} \pm 0 (< 533)$	1.0
4.951	159.3	1.0564	1.7086	8.47	$1.0^{+1.0}_{-1.0} (< 9.0)$	$93^{+93}_{-93} \pm 5 (< 834)$	0.9

TABLE III. The fitted resonance parameters for the decay of $e^+e^- \rightarrow K_S^0 \Xi^+ \Sigma^-$ with two solutions (I, II), including systematic uncertainty except for center-of-mass energy calibration.

Resonance	M (GeV)	Γ (GeV)	Φ (rad)	$\Gamma_{ee}\mathcal{B}(\times 10^{-3} \text{ eV})$	$\mathcal{B}(\times 10^{-6})$	n	c_0	$\mathcal{S}(\sigma)$
$\psi(3770)^{\text{I}}$	3.7737 (fixed)	0.0272 (fixed)	-0.6 ± 0.1	$6.6^{+4.8}_{-3.2}$	$25.3^{+18.4}_{-12.3}$	$7.9^{+0.2}_{-0.2}$	$199.6^{+61.9}_{-48.0}$	0.9
$\psi(3770)^{\text{II}}$	3.7737 (fixed)	0.0272 (fixed)	-1.4 ± 0.1	$159.6^{+8.8}_{-8.4} (< 173.0)$	$611.2^{+33.7}_{-32.2} (< 662.5)$	$7.9^{+0.2}_{-0.2}$	$202.9^{+62.9}_{-48.9}$	0.9
$\psi(4040)^{\text{I}}$	4.0400 (fixed)	0.0840 (fixed)	0.7 ± 0.9	$1.2^{+3.2}_{-1.2}$	$1.4^{+3.7}_{-1.4}$	$6.9^{+2.2}_{-2.1}$	$46.0^{+15.8}_{-11.4}$	0.3
$\psi(4040)^{\text{II}}$	4.0400 (fixed)	0.0840 (fixed)	-1.6 ± 0.1	$375.3^{+43.9}_{-44.8} (< 473.0)$	$438.4^{+51.3}_{-52.3} (< 552.6)$	$6.9^{+2.2}_{-2.1}$	$48.8^{+17.4}_{-12.2}$	0.3
$\psi(4160)^{\text{I}}$	4.1910 (fixed)	0.0690 (fixed)	1.1 ± 0.9	$0.0^{+0.0}_{-0.0}$	$0.0^{+0.0}_{-0.0}$	$6.7^{+1.6}_{-1.5}$	$36.4^{+9.0}_{-6.4}$	0.0
$\psi(4160)^{\text{II}}$	4.1910 (fixed)	0.0690 (fixed)	-1.6 ± 0.3	$249.6^{+13.7}_{-12.8} (< 275.0)$	$524.3^{+28.8}_{-26.9} (< 577.6)$	$6.7^{+1.6}_{-1.6}$	$37.2^{+9.3}_{-7.2}$	0.0
$Y(4230)^{\text{I}}$	4.2222 (fixed)	0.0510 (fixed)	-1.3 ± 2.0	$0.0^{+0.0}_{-0.0}$	...	$6.7^{+0.1}_{-0.1}$	$34.5^{+7.3}_{-5.9}$	0.0
$Y(4230)^{\text{II}}$	4.2222 (fixed)	0.0510 (fixed)	-1.6 ± 0.2	$164.5^{+9.9}_{-9.4} (< 188.0)$	...	$6.7^{+0.1}_{-0.1}$	$34.7^{+7.3}_{-6.0}$	0.0
$Y(4360)^{\text{I}}$	4.3740 (fixed)	0.1200 (fixed)	1.8 ± 0.2	$4.5^{+2.3}_{-1.8}$	...	$7.1^{+0.2}_{-0.2}$	$62.0^{+17.7}_{-13.3}$	2.8
$Y(4360)^{\text{II}}$	4.3740 (fixed)	0.1200 (fixed)	-1.7 ± 0.1	$372.0^{+20.7}_{-19.4} (< 412.0)$	...	$7.1^{+0.2}_{-0.2}$	$65.7^{+19.4}_{-14.4}$	2.8
$\psi(4415)^{\text{I}}$	4.4150 (fixed)	0.1100 (fixed)	2.7 ± 0.3	$4.5^{+2.5}_{-1.8}$	$4.3^{+2.4}_{-1.8}$	$7.0^{+0.2}_{-0.2}$	$50.3^{+13.7}_{-10.4}$	2.9
$\psi(4415)^{\text{II}}$	4.4150 (fixed)	0.1100 (fixed)	-1.8 ± 0.1	$301.5^{+19.8}_{-19.0} (< 350.0)$	$291.6^{+19.1}_{-18.4} (< 338.5)$	$7.0^{+0.2}_{-0.2}$	$52.3^{+14.4}_{-11.0}$	2.9
$Y(4500)^{\text{I}}$	4.4847 (fixed)	0.1111 (fixed)	-3.1 ± 0.7	$3.6^{+2.4}_{-1.7}$	...	$6.7^{+0.1}_{-0.1}$	$36.4^{+7.6}_{-6.2}$	2.0
$Y(4500)^{\text{II}}$	4.4847 (fixed)	0.1111 (fixed)	-1.7 ± 0.1	$265.5^{+29.0}_{-29.7} (< 332.0)$	...	$6.7^{+0.1}_{-0.1}$	$36.4^{+7.6}_{-6.2}$	2.0
$Y(4660)^{\text{I}}$	4.6230 (fixed)	0.0550 (fixed)	2.3 ± 0.3	$3.7^{+2.3}_{-1.8}$	...	$6.8^{+1.4}_{-1.4}$	$42.6^{+9.3}_{-7.5}$	2.7
$Y(4660)^{\text{II}}$	4.6230 (fixed)	0.0550 (fixed)	-1.7 ± 0.1	$169.8^{+12.4}_{-12.1} (< 198.0)$	...	$6.9^{+0.1}_{-0.1}$	$42.8^{+9.4}_{-7.6}$	2.7
$Y(4710)^{\text{I}}$	4.7080 (fixed)	0.1260 (fixed)	-2.4 ± 0.2	$21.3^{+15.6}_{-9.0}$	...	$6.6^{+0.2}_{-0.2}$	$32.3^{+8.4}_{-6.5}$	0.8
$Y(4710)^{\text{II}}$	4.7080 (fixed)	0.1260 (fixed)	-1.9 ± 0.1	$157.5^{+26.3}_{-31.3} (< 216.0)$	...	$6.6^{+0.2}_{-0.2}$	$32.7^{+8.5}_{-6.7}$	0.8

- [1] N. Brambilla *et al.*, *Eur. Phys. J. C* **71**, 1534 (2011).
[2] R. A. Briceno *et al.*, *Chin. Phys. C* **40**, 042001 (2016).
[3] X. Wang, X. Liu, and Y. Gao, *Rev. Mod. Phys.* **98**, 021001 (2026).
[4] Z.-Y. Bai, D.-Y. Chen, Qi-Huang, X. Liu, S.-Q. Luo, and J.-Z. Wang, *arXiv:2602.19887*.
[5] S. Navas *et al.* (Particle Data Group), *Phys. Rev. D* **110**, 030001 (2024).
[6] B. Aubert *et al.* (BABAR Collaboration), *Phys. Rev. Lett.* **95**, 142001 (2005).
[7] B. Aubert *et al.* (BABAR Collaboration), *Phys. Rev. Lett.* **98**, 212001 (2007).
[8] X. L. Wang *et al.* (Belle Collaboration), *Phys. Rev. Lett.* **99**, 142002 (2007).
[9] C. Z. Yuan *et al.* (Belle Collaboration), *Phys. Rev. Lett.* **99**, 182004 (2007).
[10] G. Pakhlova *et al.* (Belle Collaboration), *Phys. Rev. Lett.* **101**, 172001 (2008).
[11] J. P. Lees *et al.* (BABAR Collaboration), *Phys. Rev. D* **86**, 051102 (2012).
[12] Z. Q. Liu *et al.* (Belle Collaboration), *Phys. Rev. Lett.* **110**, 252002 (2013).
[13] J. P. Lees *et al.* (BABAR Collaboration), *Phys. Rev. D* **89**, 111103 (2014).
[14] X. L. Wang *et al.* (Belle Collaboration), *Phys. Rev. D* **91**, 112007 (2015).
[15] T. E. Coan *et al.* (CLEO Collaboration), *Phys. Rev. Lett.* **96**, 162003 (2006).
[16] M. Ablikim *et al.* (BESIII Collaboration), *Phys. Rev. Lett.* **114**, 092003 (2015).
[17] M. Ablikim *et al.* (BESIII Collaboration), *Phys. Rev. Lett.* **133**, 081901 (2024).
[18] J.-Z. Wang, D.-Y. Chen, X. Liu, and T. Matsuki, *Phys. Rev. D* **99**, 114003 (2019).
[19] R.-Q. Qian, Q. Huang, and X. Liu, *Phys. Lett. B* **833**, 137292 (2022).
[20] M. Ablikim *et al.* (BESIII Collaboration), *Phys. Rev. D* **87**, 112011 (2013).
[21] M. Ablikim *et al.* (BESIII Collaboration), *Phys. Rev. Lett.* **120**, 132001 (2018).
[22] M. Ablikim *et al.* (BESIII Collaboration), *Phys. Rev. Lett.* **124**, 032002 (2020).
[23] M. Ablikim *et al.* (BESIII Collaboration), *Phys. Lett. B* **820**, 136557 (2021).
[24] M. Ablikim *et al.* (BESIII Collaboration), *Phys. Rev. D* **105**, L011101 (2022).
[25] M. Ablikim *et al.* (BESIII Collaboration), *Phys. Rev. D* **104**, L091104 (2021).
[26] M. Ablikim *et al.* (BESIII Collaboration), *J. High Energy Phys.* **11** (2023) 228.
[27] M. Ablikim *et al.* (BESIII Collaboration), *Phys. Rev. Lett.* **131**, 191901 (2023).

- [28] M. Ablikim *et al.* (BESIII Collaboration), *J. High Energy Phys.* **05** (2024) 022.
- [29] M. Ablikim *et al.* (BESIII Collaboration), *J. High Energy Phys.* **07** (2024) 258.
- [30] M. Ablikim *et al.* (BESIII Collaboration), *J. High Energy Phys.* **11** (2024) 062.
- [31] M. Ablikim *et al.* (BESIII Collaboration), *Phys. Rev. D* **111**, L051502 (2025).
- [32] M. Ablikim *et al.* (BESIII Collaboration), *J. High Energy Phys.* **11** (2025) 111.
- [33] R. Zhang and X. Wang, *Nucl. Phys.* **B1025**, 117388 (2026), <https://www.sciencedirect.com/science/article/pii/S0550321326000969?via%3Dihub>.
- [34] M. Ablikim *et al.* (BESIII Collaboration), *arXiv:2602.23835*.
- [35] R. Zhang and X. Wang, *Symmetry* **18**, 200 (2026).
- [36] M. Ablikim *et al.* (BESIII Collaboration), *arXiv:2605.19780*.
- [37] M. Ablikim *et al.* (BESIII Collaboration), *arXiv:2606.22762*.
- [38] M. Ablikim *et al.* (BESIII Collaboration), *arXiv:2606.22759*.
- [39] M. Ablikim (BESIII Collaboration), *Chin. Phys. C* **37**, 123001 (2013).
- [40] M. Ablikim *et al.* (BESIII Collaboration), *Chin. Phys. C* **39**, 093001 (2015).
- [41] M. Ablikim *et al.* (BESIII Collaboration), *Chin. Phys. C* **46**, 113002 (2022).
- [42] M. Ablikim *et al.* (BESIII Collaboration), *Chin. Phys. C* **46**, 113003 (2022).
- [43] M. Ablikim *et al.* (BESIII Collaboration), *Chin. Phys. C* **48**, 093001 (2024).
- [44] M. Ablikim *et al.* (BESIII Collaboration), *Chin. Phys. C* **48**, 123001 (2024).
- [45] M. Ablikim *et al.* (BESIII Collaboration), *Nucl. Instrum. Methods Phys. Res., Sect. A* **614**, 345 (2010).
- [46] C. Yu *et al.*, in *7th International Particle Accelerator Conference* (JACoW, Geneva, Switzerland, 2016), p. TUYA01.
- [47] S. Agostinelli *et al.* (GEANT4 Collaboration), *Nucl. Instrum. Methods Phys. Res., Sect. A* **506**, 250 (2003).
- [48] S. Jadach, B. F. L. Ward, and Z. Was, *Comput. Phys. Commun.* **130**, 260 (2000).
- [49] S. Jadach, B. F. L. Ward, and Z. Was, *Phys. Rev. D* **63**, 113009 (2001).
- [50] R.-G. Ping, *Chin. Phys. C* **32**, 599 (2008).
- [51] D. J. Lange, *Nucl. Instrum. Methods Phys. Res., Sect. A* **462**, 152 (2001).
- [52] J. C. Chen, G. S. Huang, X. R. Qi, D. H. Zhang, and Y. S. Zhu, *Phys. Rev. D* **62**, 034003 (2000).
- [53] M. Ablikim *et al.* (BESIII Collaboration), *J. High Energy Phys.* **11** (2021) 217.
- [54] W. Sun, T. Liu, M. Jing, L. Wang, B. Zhong, and W. Song, *Front. Phys. (Beijing)* **16**, 64501 (2021).
- [55] F. Jegerlehner and R. Szafron, *Eur. Phys. J. C* **71**, 1632 (2011).
- [56] M. Ablikim *et al.* (BESIII Collaboration), *Phys. Lett. B* **820**, 136576 (2021).
- [57] M. Ablikim *et al.* (BESIII Collaboration), *Phys. Rev. D* **93**, 072003 (2016).
- [58] M. Ablikim *et al.* (BESIII Collaboration), *Phys. Rev. D* **106**, L091101 (2022).
- [59] M. Ablikim *et al.* (BESIII Collaboration), *J. High Energy Phys.* **12** (2022) 016.
- [60] M. Ablikim *et al.* (BESIII Collaboration), *J. High Energy Phys.* **12** (2023) 027.
- [61] X.-H. Mo and Y.-S. Zhu, *Chin. Phys. C* **27**, 371 (2003), <https://hepnp.ihep.ac.cn/article/id/3b0d9cec-e6d8-4f3e-ae03-43a716d83ed4>.
- [62] X.-H. Mo, *Chin. Phys. C* **30**, 140 (2006), <https://hepnp.ihep.ac.cn/en/article/id/6965e096-33eb-49f5-8315-8cfc7937bf51>.
- [63] X.-H. Mo, *Chin. Phys. C* **31**, 745 (2007), <https://hepnp.ihep.ac.cn/en/article/id/3a9524db-6254-4680-9e87-4693cd2cd82a>.
- [64] M. Ablikim *et al.* (BESIII Collaboration), *Chin. Phys. C* **46**, 111002 (2022).
- [65] M. Ablikim *et al.* (BESIII Collaboration), *Phys. Rev. Lett.* **131**, 211902 (2023).
- [66] Y.-S. Zhu, *Chin. Phys. C* **32**, 363 (2008).
- [67] M. Ablikim *et al.* (BESIII Collaboration), *Chin. Phys. C* **40**, 063001 (2016).
- [68] M. Ablikim *et al.* (BESIII Collaboration), *Chin. Phys. C* **45**, 103001 (2021).
- [69] M. Ablikim *et al.* (BESIII Collaboration), *Phys. Lett. B* **753**, 629 (2016).
- [70] F. E. Close and P. R. Page, *Phys. Lett. B* **628**, 215 (2005).
- [71] <https://cstr.cn/31109.02.BEPC>.

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