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Study of decay $\psi(1S,2S) \rightarrow$ baryon pairs at BESIII

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The BESIII detector at Beijing Electron-Positron Collider has collected the world's largest statistics of J/ψ and $\psi(3686)$ events, which provide a good laboratory for both testing Quantum Chromodynamics in the perturbative energy regime and studying the properties of baryons. This talk focuses on the two-body baryonic decays of J/ψ and $\psi(3686)$ on BESIII experiment and gives a list of corresponding measurements by BESIII Collaboration.

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1. Introduction

Baryons are three-quark composite configuration hadrons with zero net color charge. The structure of baryons is comparatively more complicated than that for mesons and the theoretical research in the area of baryonic decays is still limited. Till now, the ground baryonic states are well established in non-relativistic constituent quark model, but the excited baryon spectrum is less clear. Therefore, the study of baryonic decays is still an important field, which plays an irreplaceable role in the understanding of the hadron structure and the quark interactions.

The discovery of the J/ψ as well as $\psi(3686)$ particles opened a new epoch of hadronic physics. Many theoretical concepts and tools have been put forth to describe features of charmonium decays. These charmonium particles with a $J^{PC} = 1^{--}$ can be accumulated in large quantities via e^+e^- collision, and the subsequent decay modes are simpler than that for hadron collider. The study of baryonic decays based on e^+e^- collider will be large statistics and low contamination.

The BESIII detector [1] at the Beijing Electron-Positron Collider (BEPCII) [2] is one of the famous e^+e^- collision experiments. 1310.6×10^6 J/ψ events [3] and 447.9×10^6 $\psi(3686)$ events [4] have been collected by BESIII experiment. Based on these world's largest data samples, the baryonic decays can be studied with higher precisions. In this talk, we focus on the recent results of two-body baryonic decays from BESIII Collaboration.

2. Study of $J/\psi \to p\bar{p}$, $n\bar{n}$

Based on the isospin conservation, the strong-decay amplitudes for both $p\bar{p}$ and $n\bar{n}$ decays should be equal to zero, and the electromagnetic (EM) amplitudes of them are expected to be of the same magnitude with opposite signs. The magnitude of EM amplitude of J/ψ can be estimated from the cross section for continuum production $e^+e^- \to p\bar{p}$. According to pQCD [5, 6, 7, 8, 9], the ratio between the branching fractions for $J/\psi \to p\bar{p}$ and $J/\psi \to n\bar{n}$ can be used to estimate the phase ϕ between the strong and EM amplitudes.

Based on $(225.3 \pm 2.8) \times 10^6$ J/ψ events, the branching fractions for $J/\psi \to p\bar{p}$ and $J/\psi \to n\bar{n}$ decays are determined [10]. The phase ϕ is also found to be $\phi = \cos^{-1}[(\mathscr{B}(J/\psi \to p\bar{p}) - S^2 - E_p^2)/(2SE_p)] = (88.7 \pm 8.1)^\circ$, where S and E are the strong and EM amplitudes, respectively. This determination confirms the orthogonality of the strong and EM amplitudes within the precision of our measurement. Additional, the angular distributions can be decomposed as $|C_N^M|^2(1+\cos^2\theta) + (2M_N/M_{J/\psi})^2|C_N^E|^2\sin^2\theta$, where C_N^M and C_N^E are the total helicity ± 1 and 0 decay amplitudes. Based on the measured α values, the ratios of amplitudes for $J/\psi \to p\bar{p}$ and $J/\psi \to n\bar{n}$ decays in this measurement permit discrimination among different proposed models [10].

3. First observation of $J/\psi \to \Lambda\bar{\Sigma}^0 + c.c.$

According to $SU(3)$ group symmetry, only the two-body baryonic decays, such as $B_1\bar{B}_1$, $B_8\bar{B}_8$ and $B_{10}\bar{B}_{10}$, are allowed, with the same decay amplitudes within a given decay family if EM contributions are neglected. Nevertheless, $SU(3)$ symmetry can be broken in several ways [11]. So in phenomenological analyses, both symmetric and symmetry-breaking terms have to be included. As a specific example, the parameterization forms for octet-baryon-pair final state are worked out and presented in Table 1.

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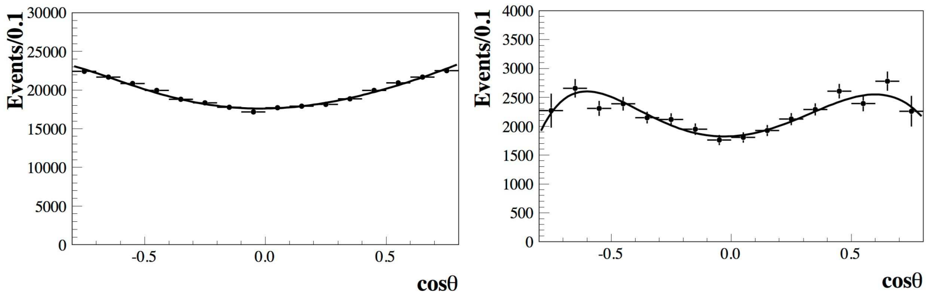

Figure 1: Angular distributions of $\cos\theta$ for p in $J/\psi \to p\bar{p}$ (left) and n in $J/\psi \to n\bar{n}$.

Decay mode	Amplitude	$\mathscr{B}(\times 10^{-3})$
$p\bar{p}$	$A + e^{i\theta}(D+F) + D' + F'$	(2.112 ± 0.031) [10]
$n\bar{n}$	$A - e^{i\theta}(2D) + D' + F'$	(2.07 ± 0.17) [10]
$\Sigma^+\bar{\Sigma}^-$	$A + e^{i\theta}(D+F) - 2D'$	(1.50 ± 0.24) [15]
$\Sigma^0\bar{\Sigma}^0$	$A + e^{i\theta}(D) - 2D'$	(1.29 ± 0.09) [15]
$\Xi^0\bar{\Xi}^0$	$A - e^{i\theta}(2D) + D' - F'$	(1.20 ± 0.24) [15]
$\Xi^-\bar{\Xi}^+$	$A + e^{i\theta}(D-F) + D' - F'$	(0.85 ± 0.16) [15]
$\Lambda\bar{\Lambda}$	$A - e^{i\theta}(D) + 2D'$	(1.61 ± 0.15) [15]
$\bar{\Lambda}\Sigma^0(\Lambda\bar{\Sigma}^0)$	$(\sqrt{3}D)$	(0.014 ± 0.002) [14]

Table 1: Amplitude parameterizations from [11, 12, 13] for J/ψ decay to a pair of octet baryons. General expressions in terms of singlet A, as well as symmetric and antisymmetric charge-breaking (D, F) and mass-breaking terms (D, F) are given. θ is the relative phase between one-photon and gluon mediated hadronic decay amplitude.

The measurement of the isospin violating decay $J/\psi \to \Lambda\bar{\Sigma}^0 + c.c.$ is important to determined the symmetric charge-breaking term D on understanding the mechanisms of the $J/\psi \to B_8\bar{B}_{10}$ decays where the large A-term is absent [11, 12]. A constraint fit to the reported branching fractions is performed to extract the values of parameters A, F, D', F' and θ using the amplitude parameterizations [13] with D fixed to 0. Based on $(225.3 \pm 2.8) \times 10^6$ J/ψ events, the value of D is updated [10], the new fit results of the phase θ changed significantly from $(76 \pm 11)^\circ$ to $(106 \pm 8)^\circ$ while the A, D', F and F' values are consistent with those from Ref. [13].

4. Study of "12% rule" and angular distribution in baryon anti-baryon pair decays

The ψ (in the following, ψ denotes both J/ψ and $\psi(3686)$) production in e^+e^- annihilation and the subsequent two-body hadronic decays, such as baryon anti-baryon pair decays, are expected to proceed via the annihilation of $c\bar{c}$ into three gluons or a virtual photon. This model also leads to the prediction that the ratio of the branching fractions of ψ decays to a specific final state should follow the so-called "12% rule" [16]. This rule was subsequently further tested in a wide variety of experimental measurements [15] and was first observed to be violated in the process $\psi \to \rho\pi$, which is known as the "$\rho\pi$ puzzle" [17]. Recently, a review of the theoretical and experimental results concluded that the current theoretical explanations are unsatisfactory, especially for the baryon pair decays of ψ [18]. Therefore, more experimental measurements on baryon anti-baryon pair final states in the decays of ψ are desirable.

Based on the hadron helicity conservation rule, the angular distribution for the decays of $\psi \rightarrow B\bar{B}$ can be expressed as: $\frac{dN}{d(\cos\theta)} \propto 1+\alpha\cos^2\theta$, where θ is the angle between baryon and the positron beam direction. Various theoretical calculations based on first-order QCD have predicted the value of α [19, 20]. Experimental efforts are useful to measure α in order to test the hadron helicity conservation rule and study the validity of the various theoretical approaches.

4.1 Study of $J/\psi(\psi(3686)) \rightarrow \Xi^-\bar{\Xi}^+$, $\Sigma(1385)^\pm\bar{\Sigma}(1385)^\mp$

Using $(225.3\pm2.8)\times10^6$ J/ψ and $(106.4\pm0.9)\times10^6$ $\psi(3686)$ events, the branching fractions and the angular distributions for $J/\psi(\psi(3686)) \rightarrow \Xi^-\bar{\Xi}^+$, $\Sigma(1385)^\pm\bar{\Sigma}(1385)^\mp$ are measured with the single baryon tag method applied, and the fit results are shown in Fig. 2. All the angular parameter α and branching fractions for the corresponding decays are measured for the first time except that the branching fraction for $J/\psi(\psi(3686)) \rightarrow \Xi^-\bar{\Xi}^+$ decay is measured with improved precision [21]. Based on the measured branching fractions, the "12% rule" for the corresponding decays are determined to be: $\frac{\mathscr{B}(J/\psi\rightarrow\Xi^-\Xi^+)}{\mathscr{B}(\psi(3686)\rightarrow\Xi^-\Xi^+)} = (26.73\pm0.50\pm2.30)\%$, $\frac{\mathscr{B}(J/\psi\rightarrow\Sigma(1385)^+\bar{\Sigma}(1385)^-)}{\mathscr{B}(\psi(3686)\rightarrow\Sigma(1385)^+\bar{\Sigma}(1385)^-)} = (7.76\pm0.55\pm0.68)\%$ and $\frac{\mathscr{B}(J/\psi\rightarrow\Sigma(1385)^-\bar{\Sigma}(1385)^+)}{\mathscr{B}(\psi(3686)\rightarrow\Sigma(1385)^-\bar{\Sigma}(1385)^+)} = (6.68\pm0.40\pm0.50)\%$, respectively. The ratios are not in agreement with 12%, especially for the $\Xi^-\Xi^+$ mode.

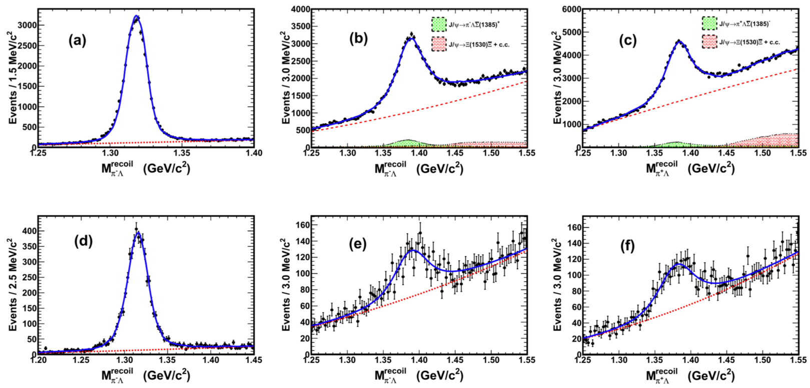

Figure 2: Recoiling mass spectra of $\pi^-\Lambda$ and $\pi^+\Lambda$. (a) $J/\psi \rightarrow \Xi^-\bar{\Xi}^+$, (b) $J/\psi \rightarrow \Sigma(1385)^-\bar{\Sigma}(1385)^+$, (c) $J/\psi \rightarrow \Sigma(1385)^+\bar{\Sigma}(1385)^-$, (d) $\psi(3686) \rightarrow \Xi^-\bar{\Xi}^+$, (e) $\psi(3686) \rightarrow \Sigma(1385)^-\bar{\Sigma}(1385)^+$, (f) $\psi(3686) \rightarrow \Sigma(1385)^+\bar{\Sigma}(1385)^-$. Dots with error bars indicate the data, the solid lines show the fit results, the dashed lines are for the combinatorial background, and the hatched histograms are for the peaking backgrounds.

4.2 Study of $J/\psi(\psi(3686)) \rightarrow \Xi^0\bar{\Xi}^0$, $\Sigma(1385)^0\bar{\Sigma}(1385)^0$

Using $(1310.6\pm7.0)\times10^6$ J/ψ and $(447.9\pm2.9)\times10^6$ $\psi(3686)$ events, the preliminary results of branching fractions and the angular distributions for $J/\psi(\psi(3686)) \rightarrow \Sigma(1385)^0\bar{\Sigma}(1385)^0$ and $\Xi^0\bar{\Xi}^0$ are measured with the same single baryon tag method applied as described in [21], and the fit results are shown in Fig. 3. All the angular parameter α and branching fractions for the corresponding decays are measured for the first time except that the branching fraction for $J/\psi(\psi(3686)) \rightarrow \Xi^0\bar{\Xi}^0$ decay is measured with improved precision. Based on the measured branching fractions, the "12% rule" for the corresponding decays are determined to be: $\frac{\mathscr{B}(J/\psi\rightarrow\Xi^0\Xi^0)}{\mathscr{B}(\psi(3686)\rightarrow\Xi^0\Xi^0)} =$

Decay mode	$\frac{\mathcal{B}(\psi\to\Xi^0\bar{\Xi}^0)}{\mathcal{B}(\psi\to\Xi^-\bar{\Xi}^+)}$	$\frac{\mathcal{B}(\psi\to\Sigma(1385)^0\bar{\Sigma}(1385)^0)}{\mathcal{B}(\psi\to\Sigma(1385)^-\bar{\Sigma}(1385)^+)}$	$\frac{\mathcal{B}(\psi\to\Sigma(1385)^0\bar{\Sigma}(1385)^0)}{\mathcal{B}(\psi\to\Sigma(1385)^+\bar{\Sigma}(1385)^-)}$
J/ψ	$1.09\pm0.07\pm0.09$	$0.98\pm0.01\pm0.10$	$0.85\pm0.01\pm0.08$
$\psi(3686)$	$0.96\pm0.02\pm0.07$	$0.92\pm0.10\pm0.09$	$0.93\pm0.09\pm0.09$

Table 2: Summary of branching fraction ratios for testing isospin symmetry. The first uncertainties are the statistical one, and the seconds are systematic.

$(23.65\pm0.27\pm1.39)\%$ and $\frac{\mathcal{B}(J/\psi\to\Sigma(1385)^0\bar{\Sigma}(1385)^0)}{\mathcal{B}(\psi(3686)\to\Sigma(1385)^0\bar{\Sigma}(1385)^0)} = (7.28\pm0.56\pm0.75)\%$, respectively. The ratios are not in agreement with 12%, especially for the $\Xi^0\Xi^0$ mode.

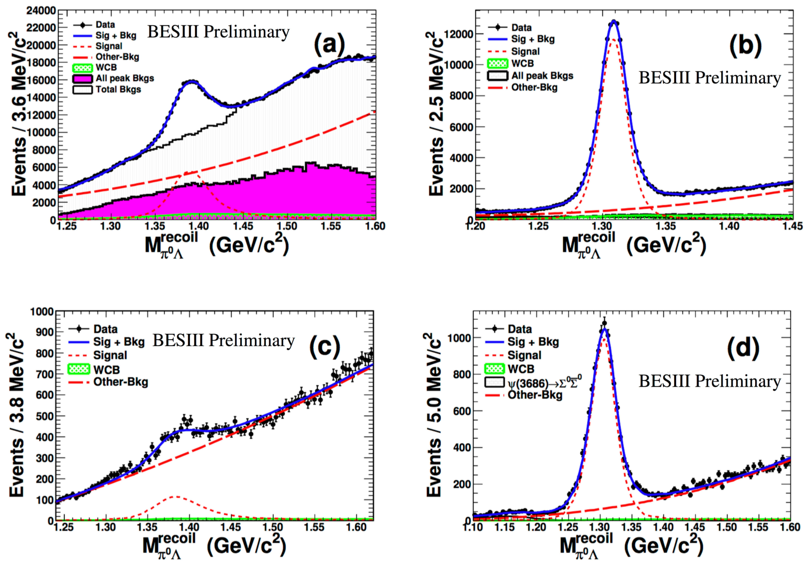

Figure 3: Recoiling mass spectra of $\pi^0\Lambda$. (a) $J/\psi \to \Sigma(1385)^0\bar{\Sigma}(1385)^0$, (b) $J/\psi \to \Xi^0\bar{\Xi}^0$, (c) $\psi(3686) \to \Sigma(1385)^0\bar{\Sigma}(1385)^0$, (d) $\psi(3686) \to \Xi^0\bar{\Xi}^0$. Dots with error bars indicate the data, the solid line shows the fit results, the dashed lines are for signal and the remaining background (Other-Bkg), and the hatched ones are for wrong combination background (WCB) and the peaking background.

Based on the neutral and charged decay modes of $\psi \to \Xi\bar{\Xi}$ and $\Sigma(1385)\bar{\Sigma}(1385)$, the isospin symmetry can be tested by comparing the branching fractions of corresponding decays. The branching fraction ratios are listed in Table 2, which are well within one time of standard derivation of the expectation of isospin symmetry.

4.3 Study of $J/\psi(\psi(3686)) \to \Lambda\bar{\Lambda}$, $\Sigma^0\bar{\Sigma}^0$

By analyzing 1310.6×10^6 J/ψ events and 447.9×10^6 $\psi(3686)$ events, the preliminary results of branching fractions and angular parameter α for $\psi \to B\bar{B}$ decays ($J/\psi \to \Lambda\bar{\Lambda}$, $J/\psi \to \Sigma^0\bar{\Sigma}^0$, $\psi(3686) \to \Lambda\bar{\Lambda}$ and $\psi(3686) \to \Sigma^0\bar{\Sigma}^0$) are extracted with double baryon tag method applied, both the baryon and anti-baryon are well reconstructed in the selection. The α values for $\psi(3686) \to \Lambda\bar{\Lambda}$ and $\psi(3686) \to \Sigma^0\bar{\Sigma}^0$ decays are measured for the first time (Fig. 4) and all the other preliminary results agree with the most recent measurements with greatly improved precisions [15].

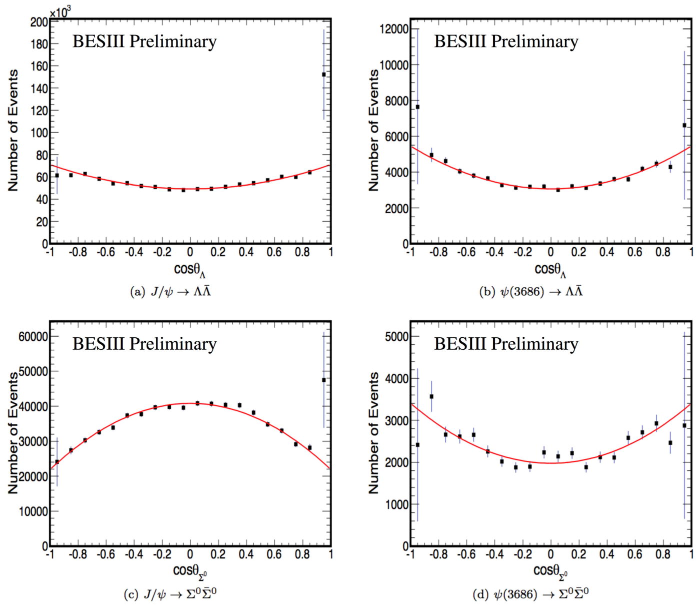

Figure 4: Fits to the angular distribution for (a) $J/\psi \to \Lambda\bar{\Lambda}$, (b) $J/\psi \to \Sigma^0\bar{\Sigma}^0$, (c) $\psi(3686) \to \Lambda\bar{\Lambda}$ and (d) $\psi(3686) \to \Sigma^0\bar{\Sigma}^0$.

To test the "12% rule", the ratios of the branching fractions between J/ψ and $\psi(3686)$ decays are determined to be $\frac{\mathscr{B}(\psi(3686)\to\Lambda\bar{\Lambda})}{\mathscr{B}(J/\psi\to\Lambda\bar{\Lambda})}=(20.35\pm0.16\pm0.62)\%$ and $\frac{\mathscr{B}(\psi(3686)\to\Sigma^0\bar{\Sigma}^0)}{\mathscr{B}(J/\psi\to\Sigma^0\bar{\Sigma}^0)}=(21.07\pm 0.28\pm0.87)\%$, respectively. The ratios are not in agreement with "12%" in both of the $\Lambda\bar{\Lambda}$ and $\Sigma^0\bar{\Sigma}^0$ decays modes.

5. Summary

In summary, based on up to 1310.6×10^6 J/ψ events and 447.9×10^6 $\psi(3686)$ events collected by BESIII detector at BEPCII collider, the two-body baryonic decays are studied. The recent results from BESIII Collaboration are shown in this talk, more measurements about baryonic decays are in progress, which provide a powerful tool to study the baryon structure and the quark interaction. These measurements will also provide complementary information to other experiments.

References

[1] M. Ablikim *et al.* (BESIII Collaboration), *Design and construction of the BESIII Detector*, Nucl. Instrum. Meth. A **614** (2010) 345.

[2] C. Zhang, *Studies on BEPC upgrade from pretzel to double-ring*, Sci. China G **53** (2010) 2084.

[3] M. Ablikim *et al.* (BESIII Collaboration), *Determination of the number of J/ψ events with $J/\psi \to$ inclusive decays*, Chin. Phys. C **36** (2012) 915; M. Ablikim *et al.* (BESIII Collaboration), Chin. Phys. C (to be published).

[4] M. Ablikim *et al.* (BESIII Collaboration), *Determination of the number of ψ' events at BESIII*, Chin. Phys. C **37** (2013) 063001; The total number of $\psi(3686)$ events is obtained based on the same method. The preliminary number is determined to be 447.9×10^6 with uncertainties of 0.65%.

[5] R. Baldini, C. Bini, E. Luppi, *Measuring the phase of the J/ψ strong decay amplitudes*, Phys. Lett. B **404** (1997) 362.

[6] C. Yuan, P. Wang, X. Mo, *Relative phase between strong and electromagnetic amplitudes in $\psi(2S) \to 0^-0^-$ decays*, Phys. Lett. B **567** (2003) 73.

[7] P. Wang, C. Yuan, X. Mo, *Possible large phase in $\psi(2S) \to 1^-0^-$ decays*, Phys. Rev. D **69** (2004) 057502.

[8] V. Chemyak, I. Zhitnitsky, *Nucleon Wave Function and Nucleon Form-Factors in QCD*, Nucl. Phys. B **246** (1984) 52.

[9] C. Carimalo, *Quark Mass Effects in $\psi \to B\bar{B}$ Decays* , Int. J. Mod. Phys. A **2** (1987) 249.

[10] M. Ablikim *et al.* (BESIII Collaboration), *Study of $J/\psi \to p\bar{p},\ n\bar{n}$*, Phys. Rev. D **86** (2012) 032014.

[11] L. Kopke, N. Wermes, *J/ψ Decays*, Phys. Rept. **174** (1989) 67.

[12] H. Kowalski, T. Walsh, *Interference Effects in J/ψ Decay*, Phys. Rev. D **14** (1976) 852.

[13] D. Wei, *The $SU(3)$ symmetry breaking in J/ψ decays*, J. Phys. G **36** (2009) 115006.

[14] M. Ablikim *et al.* (BESIII Collaboration), *First observation of the isospin violating decay $J/\psi \to \Lambda\bar{\Sigma}^0 + c.c.$*, Phys. Rev. D **86** (2012) 032008.

[15] C. Amsler *et al.* (Particle Data Group), *The Review of Particle Physics*, J. Phys. G **37** (2010) 075021.

[16] W. Hou, *Glueballs: Charmonium decay and anti-p p annihilation*, Phys. Rev. D **55** (1997) 6956.

[17] Q. Wang, G. Li, Q. Zhao, *Open charm effects in the explanation of the long-standing '$\rho\pi$ puzzle'* , Phys. Rev. D **85** (2012) 074015.

[18] N. Brambilla, *Heavy quarkonium: progress, puzzles, and opportunities*, Eur. Phys. J. C **71** (2011) 1534.

[19] M. Claudson, S. Glashow, M. Wise, *Isospin Violation in $J/\psi \to$ Baryon Anti-baryon*, Phys. Rev. D **25** (1982) 1345.

[20] C. Carimalo, *Quark Mass Effects in $\psi \to B\bar{B}$ Decays*, Int. J. Mod. Phys. A **2** (1987) 249.

[21] M. Ablikim *et al.* (BESIII Collaboration), *Study of ψ decays to the $\Xi^-\bar{\Xi}^+$ and $\Sigma(1385)^{\pm}\bar{\Sigma}(1385)^{\mp}$ final states*, Phys. Rev. D **93** (2016) 072003.