Proceedings of the Pakistan Academy of Sciences:
A. Physical and Computational Sciences 55 (2): 1–11 (2018)

ISSN: 2518-4245 (print), 2518-4253 (online)

Pakistan Academy of Sciences

Review Article

Significance of Strangeness Conservation/Violation Studies at BESIII

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Abstract Strangeness violation and conservation have been studied in Charmonia and its higher state decays. The data of some prominent decay modes has been collected from BESIII laboratory from the years 2009 to date. The strangeness violating decays play an important role in the study of weak interactions. On the other hand, strangeness conserving decays describe the strong interactions. An overview of strangeness conserving decays and strangeness violating decays has been given and the decay modes are presented in tabular form. The study reveals that associated production occurs only in strangeness conserving decays rather than strangeness violating decays. Experimental and theoretical results are presented in order to arrange phenomenological developments and queries may search new domains in Experimental High Energy Physics, and will explore new prospects of strangeness, a basic quantum number of hadrons and its associated production.

Keywords: Strangeness, Charmonia, Strangeness conserving decays, Strangeness violating decays, Standard model

1. INTRODUCTION

The study of particles and the interaction between them shows that quarks and leptons are the basic constituents of matter [1]. These quarks exist in bound states. There are six type of quarks, named as, up (u), down (d), strange (s), charm (c), bottom (b), top (t) quark. Similarly, there are six type of leptons, electron(e) , muon(μ) and tau(τ) alongwith their neutrinos electron neutrinos(ν_e), muon neutrino(ν_μ) and tau neutrino(ν_τ) [2].

According to the quark model, these quarks are combined together to form hadrons. Hadrons are strongly interacting particles and are divided into two categories, named as, Baryons and Mesons [3]. In 1960, these particles are arranged in Eightfold way-classification according to their quantum numbers. Baryons consist of three quarks or three anti-quarks. Mesons consist of a quark and anti-quark. The baryons and mesons are arranged into octets and decuplets according to their spin, charge and strange quantum numbers. This classification of baryon and meson is shown in the Fig. 1 to Fig. 4.

In 1970, a new theory was predicted which described the interactions among these particles known as Standard Model. According to Standard Model, three types of interactions exist among these particles i.e. electromagnetic, strong and weak interaction [4-5].

In this paper, all those decay processes have been studied in which strangeness exists. These processes involve strange baryons and strange mesons and the list of these strange mesons and baryons are listed in Table 1 and Table 2 respectively. The data involving strangeness has been collected from BESIII Laboratory for the period 2009 to 2017. It was observed that some decay processes are those in which law of conservation of strangeness holds. This fact is according to the theory of Standard Model. On the other hand, some strangeness violating reactions have also been observed in BESIII, which show that evidences for the strangeness violations are increasing day by day. Such kind of decays, showing weak interactions are discussed and highlighted in many decay modes in BESIII and their branching fractions have also been reported. An important property of strangeness, called associated production, has also been introduced which is very prominent in the strangeness

Received, December 2017; Accepted, June 2018
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conserving decays of Charmonia. The decays modes showing associated production are listed in the Table 3(a) to 3(d). These decay modes are governed by strong interactions only [2].

The data consisting of strangeness conserving decays and strangeness violating decays along with their branching fractions have been arranged in the Table 3(a) to 3(d) and Table 4(a) to 4(e).

2. Strangeness

Strangeness 'S' [6] is a quantity associated with all hadrons. Strangeness is basically an additive quantum number. Like baryon number, lepton number, this quantum number is assigned to all hadrons named as strangeness quantum number. It became necessary to introduce this quantum number for the study of properties of particles. The reasons for introducing this quantity are few reactions which are quite different in nature from the other decay processes. For example, in the following reaction, a proton and pion interacts very strongly to produce a Λ^0 baryon.

$$\pi^- + P \longrightarrow \Lambda^0 + K^0$$
$$\pi^0 + P \longrightarrow \Lambda^0 + K^+$$

Here Λ^0 is the baryon with mass $M_{\Lambda^0} = 1.115MeV$ [6]. Since Λ^0 baryon is very unstable particle, so it decays further into some other particles as shown in the following reaction;

$$\Lambda^0 \longrightarrow \pi^- + P$$

Baryon number is conserved in this reaction, therefore Λ^0 should decay via strong interaction and its life time should be of the order of $\sim 10^{-23} seconds$. But it has been observed that its decay time is of the order of $\sim 10^{-8} seconds$ which is approximately equal to the life time of weak decays. So Λ^0 baryon decays via weak interaction and it shows strange behavior [6].

A similar strange behavior has been observed in the decay of kaon meson. This reaction is also given below;

$$K^+ \longrightarrow \pi^+ + \pi^0$$

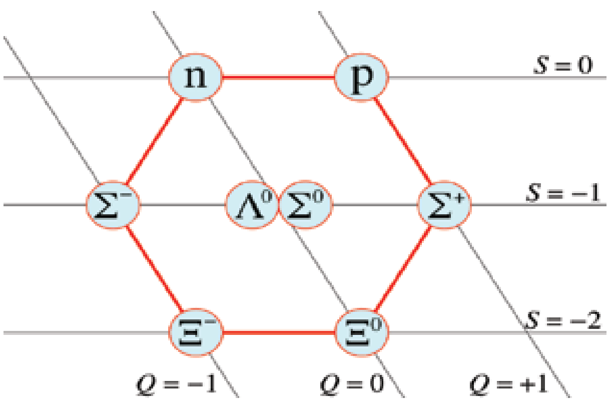

Figure 1. The spin ½ baryons arranged in baryon octet [4-5]

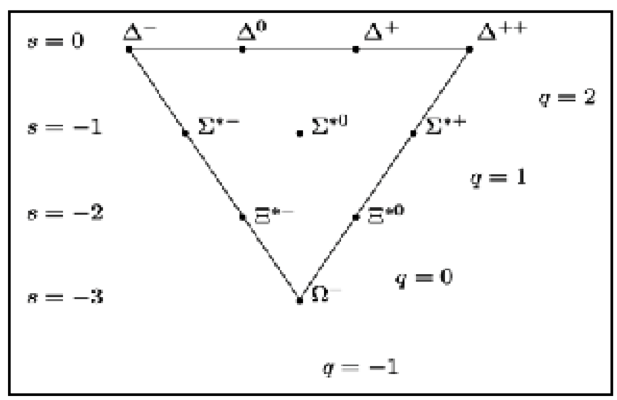

Figure 2. The spin 3⁄2 baryons arranged in baryon decu-plets [4-5].

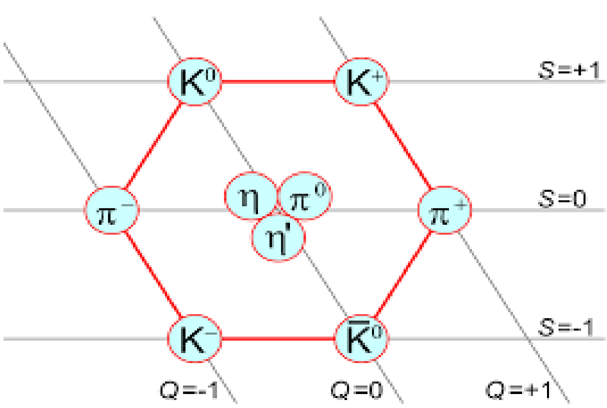

Figure 3. The meson nonet with spin 0 [4-5]

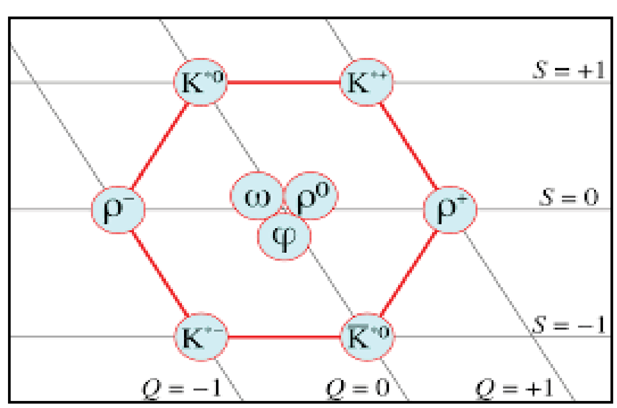

Figure 4. The meson nonet with spin 1 [4-5]

This decay has baryon number $B = 0$. So it must be carried out via strong interaction. But this does not happen. Its life time is again observed to be $10^{-8} sec$ rather than $10^{-23} sec$ which shows that it is a weak decay. Again, this is the Strange Behavior [6]. Strangeness [6] leads to a new conservation law. This law is known as Law of Conservation of Strangeness.

Strangeness values could be 0, 1, -1. The strangeness quantum number violates in those reactions which do not decay via strong interaction but this quantum number is conserved in strong interactions. The results of three reactions indicating the strangeness conservation and strangeness violation as under;

$$\pi^0 + P \longrightarrow \Lambda^0 + K^+$$

(decays via strong interaction)

$\Lambda^0 \longrightarrow \pi^- + P$ (decays via weak intercation)

$\mathrm{K}^+ \longrightarrow \pi^+ + \pi^0$ (decays via weak interaction)

It has been observed from the above three reactions that law of strangeness is violated in the processes which decay through weak interactions and it is conserved in strong decays [6]. The conservation of strangeness via strong interaction is discussed in terms of associated production in the section below.

3. Associated Production and its Significance

In 1952, Abraham Pais observed some neutral particles (V^0's) produced in cloud chamber with larger cross section (~ 10^{-27} cm^2) and these particles decayed through smaller cross section (~ 10^{-40} cm^2) [6]. This phenomenon happened in strange particles as strange particles are produced abundantly having life time of 10^{-23} seconds but their decay time is relatively slow about 10^{-10} seconds. This shows that their production mechanism is different from their disintegration mechanism. So one can say that strong force governs the production of strange particles whereas weak force is responsible for their decay. So if a strange particle is produced in strong interaction, they are always produced in pairs of particles of opposite strangeness so as to conserve the total strangeness. This phenomenon is called Associated Production [6].

Some strange mesons have been listed in the Table 1 along with their quark contents and strangeness, $S = \pm 1$. Similarly, some strange baryons having strangeness $S = \pm 1, \pm 2, \pm 3$ are listed in the Table 2 [7]. In next section, a brief description of BESIII experimental setup is given.

Table 1. List of Strange Mesons with $S = \pm 1$ [7]

Mesons	Quark Contents	Strangeness
K^+	$u\bar{s}$	$+1$
K^-	$s\bar{u}$	-1
K^0	$d\bar{s}$	$+1$
$\bar{K}^0$	$s\bar{d}$	-1
K_S^0	$(d\bar{s} + s\bar{d})/\sqrt{2}$	(*)
K_L^0	$(d\bar{s} - s\bar{d})/\sqrt{2}$	(*)
K^{*+}	$u\bar{s}$	$+1$
K^{*0}	$d\bar{s}$	$+1$
Charmed+ Strange Mesons	Quark Contents	Strangeness
D_S^+	$c\bar{s}$	$+1$
D_S^-	$\bar{c}s$	-1
D_S^{*+}	$c\bar{s}$	$+1$
D_S^{*-}	$\bar{c}s$	-1
Bottom +Strange Mesons	Quark Contents	Strangeness
B_S^0	$s\bar{b}$	-1
$\bar{B}_S^0$	$b\bar{s}$	$+1$
B_S^{*0}	$s\bar{b}$	-1

4. BESIII Experimental Setup

This paper is about the theoretical study of strangeness conservations and violation of Charmonia, based on the data collected from BESIII detector. BESIII detector uses the BESIII offline software system (BOSS), CLHEP libraries and Root software to study the charmonium spectroscopy [8-9].

The upgraded version of BES is BESIII that consists of BEPCII $e^{-}e^{+}$ collider and BESIII detector. BESIII detector is specifically used to study the Tau-Charm Physics within energy range of 2 to 5 GeV. BESIII detector became operational from 2009 [8]. BESIII detector has four main components named as Main Drift Chamber (MDC), Electromagnetic Calorimeter (EMC), Time of Flight System (TOF) and Muon Chamber System (MUC). These parts of detector detect various particles and their specific properties such as their momentum, energy, energy losses, position and time etc. within certain energy range of Charmonia. For more detail, for example, MDC used to measure the momentum and energy loss information of charged particles. Electromagnetic Calorimeter (EMC) is used to measure the energy and position of electron and photons only. Time of Flight System (TOF) is used to measure the time of flight of charged particles from the point of interaction to the detector. Since most of the collisions processes decays into muons, so Muon Chamber (MUC) is used to detect the paths and positions of muons produced during the e^{-} e^{+} or $P\overline{P}$ collisions [8-9]. All the parts and efficiencies of BESIII experimental setup are related and much dependent on BOSS (BESIII Offline Software System) [9]**.** A brief introduction to BESIII Offline Software (BOSS) is given in next section.

5. BESIII Offline Software (BOSS)

BESIII Offline Software System (BOSS) uses the C++ language and object oriented programming and works on Scientific Linux Operating System. BESIII Offline System is based upon Gaudi Framework which provides interfaces and its utilities for simulating the data and physics analysis. Software Configuration is managed by configuration management tool (CMT). It provides different packages, libraries and their utilities. Information and specification of detector is stored in Geometrical Description Markup Language (GDML). BOSS provides many services to meet the requirement of analysis such as navigation and reconstruction of MC tracks. This Data processing and physics analysis software system has three main functions i.e. Simulation, Reconstruction and Calibration. BESIII detector simulation is based upon GEANT4 package which gives information about the detector, particle tracking and their interaction with the detector [9].

6. CHARMONIUM SPECTROSCOPY

In 1974, the discovery of charmonium meson J/ψ at BNL (Brookhaven National Laboratory) and SLAC (Stanford Linear Accelerator Center) has opened up a new horizon in the field of research. After that, some other states of charmonium were discovered at some higher energies named as ψ', η_c, $\eta_c{}'$, $\chi_{c0,c1,c2}$, h_c and D states. The decays of these charmonium and its higher states were mainly studied at BES (Beijing Electron Spectrometer) Lab [8-10].

The charmonium and its higher energy states being discussed here, contain charm quark as one of its quark content. The decays of these charmonium states are categorized as the strangeness conserving and strangeness violating decays. These decays are listed in Table 3 (a) to 3(d) and Table 4(a) to 4(e).

7. DISCUSSIONS AND CONCLUSION

Strangeness has been observed in J/ψ, ψ', η_c, $\eta_c{}'$, $\chi_{c0,c1,c2}$, h_c and D-decays. The data of these decays has been collected from BESIII Laboratory. The branching fractions of strangeness conserving and strangeness violating decays have been studied from the years 2009 to 2017. In Table 3(a), the decays of J/ψ, in which strangeness conservation occurs, are given [11-16]. Table 3(b) consists of ψ' decays containing strange baryon anti-baryon pair along with single non-strange meson to conserve the strangeness [14-22]. Table 3(c) shows only 2-body strangeness conserving decays of strange baryon-anti-baryon pair or strange meson-anti-meson pair [13, 23-24]. In the same way, 2-body, 3-body and 4-body strangeness conserving decays of χ_{cJ} are listed in table 3(d) [18, 25-28]. From this data, it is clear that associated production takes place in strangeness conserving decays. These decays are the manifestation of strong interactions.

Table 2. List of Strange Baryons [7]

Strange Baryons	**Quark Contents**	**Strangeness**
Λ	uds	-1
$\overline{\Lambda}$	$\overline{uds}$	$+1$
Sigma Strange Baryons	Quark Contents	Strangeness
Σ^{+}	uus	-1
$\Sigma^{*+}(1385)$	uus	-1
Σ^{0}	uds	-1
$\Sigma^{*0}(1385)$	uds	-1
Σ^{-}	dds	-1
$\Sigma^{*-}(1385)$	dds	-1
Xi Strange Baryons	Quark Contents	Strangeness
Ξ^{0}	uss	-2
$\Xi^{0}(1530)$	uss	-2
$\Xi^{*0}(1530)$	uss	-2
Ξ^{-}	dss	-2
$\Xi^{-}(1530)$	dss	-2
$\Xi^{*-}(1530)$	dss	-2
Ξ_{c}^{0}	dsc	-1
$\Xi_{c}^{'0}$	dsc	-1
$\Xi_{c}^{'0}(2645)$	dsc	-1
Ξ_{c}^{+}	usc	-1
$\Xi_{c}^{'+}$	usc	-1
$\Xi_{c}^{*+}(2645)$	usc	-1
Ξ_{b}^{0}	usb	-1
Ξ_{b}^{*0}	usb	-1
$\Xi_{b}^{'0}$	usb	-1
Ξ_{b}^{-}	dsb	-1
$\Xi_{b}^{'-}$	dsb	-1
Ξ_{b}^{*-}	dsb	-1
Omega Strange Baryons	Quark Contents	Strangeness
Ω^{-}	sss	-3
Ω_{b}^{-}	ssb	-2
Ω_{b}^{*-}	ssb	-2
Ω_{bb}^{-}	sbb	-1
Ω_{bb}^{*-}	sbb	-1
Ω_{c}^{0}	ssc	-2
$\Omega_{c}^{*0}(2770)$	ssc	-2
Ω_{cc}^{+}	scc	-1
Ω_{cc}^{*+}	scc	-1
Ω_{cb}^{0}	scb	-1
$\Omega_{cb}^{'0}$	scb	-1
Ω_{cb}^{*0}	scb	-1

Table 3 (a). Strangeness Conserving Decays of J/ψ States Studied at BESIII

Decay Channel	**No. of Events**	**Branching Fraction**	**Year**
$J/\psi \longrightarrow \Xi^0\overline{\Xi}^0$		$(1.2 \pm 0.24) \times 10^{-3}$	2009
$J/\psi \longrightarrow \Xi^-\Xi^+$		$(0.9 \pm 0.2) \times 10^{-3}$	
$J/\psi \longrightarrow \Sigma^0\overline{\Sigma}^0$ [11]		$(1.29 \pm 0.09) \times 10^{-5}$	
$J/\psi \longrightarrow \Sigma^0\overline{\Sigma}^0$[12]		$(1.5 \pm 0.24) \times 10^{-3}$	2009
$J/\psi \longrightarrow \Lambda\overline{\Sigma}^0$	$(225.2 \pm 2.8) \times 10^6$	$(1.37 \pm 0.12 \pm 0.11) \times 10^{-5}$	2012
$J/\psi \longrightarrow \bar{\Lambda}\Sigma^0$ [13]		$(1.46 \pm 0.11 \pm 0.12) \times 10^{-5}$	
$J/\psi \longrightarrow \Xi^0\overline{\Xi}^0$	1310.6×10^6	$(11.65 \pm 0.04) \times 10^{-4}$	2016
$J/\psi \longrightarrow \Sigma^0(1385)\overline{\Sigma}^0(1385)$[14]	1310.6×10^6	$(10.71 \pm 0.09) \times 10^{-5}$	
$J/\psi \longrightarrow \Xi^-\Xi^+$	$(223.7 \pm 14) \times 10^6$	$(0.58 \pm 0.04 \pm 0.08)$	2016
$J/\psi \longrightarrow \Sigma(1385)^-\Sigma(1385)^+$[15]	$(223.7 \pm 14) \times 10^6$	$(-0.58 \pm 0.05 \pm 0.09)$	
$J/\psi \longrightarrow \Sigma(1385)^0\overline{\Sigma}(1385)^0$	$(1310.6 \pm 7.0) \times 10^6$	$(10.71 \pm 0.09) \times 10^{-4}$	2017
$J/\psi \longrightarrow \Xi^0\overline{\Xi}^0$[16]	$(1310.6 \pm 7.0) \times 10^6$	$(11.65 \pm 0.04) \times 10^{-4}$	

Table 3 (b). Strangeness Conserving Decays of ψ'Studied at BESIII

Decay Channel	**No. of Events**	**Branching Fraction**	**year**
$\psi' \longrightarrow K_2^*(1430)^+K^- + c.c$ [17]	$(106 \pm 4) \times 10^6$	$(7.12 \pm 0.62^{+1.13}_{-0.61}) \times 10^{-5}$	2012
$\psi' \longrightarrow \bar{P}K^+\Sigma^0 + c.c$ [18]	1.06×10^8	$(1.67 \pm 0.13 \pm 0.12) \times 10^{-5}$	2013
$\psi(3686) \longrightarrow \omega K\bar{K}\pi$ [19]	1.06×10^8	$(0.878 \pm 0.233 \pm 0.096)$	2013
$\psi(3770) \longrightarrow \Lambda\overline{\Lambda}\pi^+\pi^-$ [20]		$< 4.7 \times 10^{-4}$ at C.L 90%	2013
$\psi(3770) \longrightarrow \Lambda\overline{\Lambda}\pi^0$		$< 0.7 \times 10^{-4}$ at C.L 90%	
$\psi(3770) \longrightarrow \Lambda\overline{\Lambda}\eta$		$< 1.9 \times 10^{-4}$ at C.L 90%	
$\psi(3770) \longrightarrow \Sigma^+\overline{\Sigma}^-$		$< 1.0 \times 10^{-4}$ at C.L 90%	
$\psi(3770) \longrightarrow \Sigma^0\overline{\Sigma}^0$		$< 0.4 \times 10^{-4}$ at C.L 90%	
$\psi(3770) \longrightarrow \Xi^-\overline{\Xi}^+$		$< 1.5 \times 10^{-4}$ at C.L 90%	
$\psi(3770) \longrightarrow \Xi^0\overline{\Xi}^0$		$< 1.4 \times 10^{-4}$ at C.L 90%	
$\psi(4040) \longrightarrow \Lambda\overline{\Lambda}\pi^+\pi^-$		$< 2.9 \times 10^{-4}$ at C.L 90%	
$\psi(4040) \longrightarrow \Lambda\overline{\Lambda}\pi^0$		$< 0.9 \times 10^{-4}$ at C.L 90%	
$\psi(4040) \longrightarrow \Lambda\overline{\Lambda}\eta$		$< 3.0 \times 10^{-4}$ at C.L 90%	
$\psi(4040) \longrightarrow \Sigma^+\overline{\Sigma}^-$		$< 1.3 \times 10^{-4}$ at C.L 90%	
$\psi(4040) \longrightarrow \Sigma^0\overline{\Sigma}^0$		$< 0.7 \times 10^{-4}$ at C.L 90%	
$\psi(4040) \longrightarrow \Xi^-\overline{\Xi}^+$		$< 1.6 \times 10^{-4}$ at C.L 90%	
$\psi(4040) \longrightarrow \Xi^0\overline{\Xi}^0$		$< 1.8 \times 10^{-4}$ at C.L 90%	
$\psi(3686) \longrightarrow \Lambda\overline{\Sigma}^+\pi^- + c.c$ [21]	1.06×10^8	$(1.40 \pm 0.03 \pm 0.13) \times 10^{-4}$	2013
$\psi(3686) \longrightarrow \Lambda\overline{\Sigma}^-\pi^+ + c.c$	1.06×10^8	$(1.54 \pm 0.04 \pm 0.13) \times 10^{-4}$	
$\psi(3686) \longrightarrow \omega K^+K^-$ [22]	1.06×10^8	$(1.54 \pm 0.04 \pm 0.11) \times 10^{-4}$	2014
$\psi(3686) \longrightarrow \Sigma^0(1385)\overline{\Sigma}^0(1385)$[14]	1310.6×10^6	$(0.78 \pm 0.06) \times 10^{-4}$	2016
$\psi(3686) \longrightarrow \Xi^-\Xi^+$	$(106.4 \pm 0.9) \times 10^6$	$(0.91 \pm 0.13 \pm 0.14)$	2016
$\psi(3686) \longrightarrow \Sigma(1385)^-\Sigma(1385)^+$[15]	$(106.4 \pm 0.9) \times 10^6$	$(0.64 \pm 0.40 \pm 0.27)$	
$\psi(3686) \longrightarrow \Sigma(1385)^0\overline{\Sigma}(1385)^0$	$(447.9 \pm 2.9) \times 10^6$	$(0.69 \pm 0.05) \times 10^{-4}$	2017
$\psi(3686) \longrightarrow \Xi^0\overline{\Xi}^0$[16]	$(447.9 \pm 2.9) \times 10^6$	$(2.73 \pm 0.03) \times 10^{-4}$	

Table 3 (c). Strangeness Conserving Decays of η_c Studied at BESIII

Decay Channel	No. of Events	Branching Fraction	year
$\eta_c{}' \longrightarrow K^{*0}\bar{K}^{0*}$[23]	1.06×10^8	$< 5.4 \times 10^{-3}$ at 90% C.L	2011
$\eta_c \longrightarrow \Lambda\bar{\Lambda}$[13]	$(225.2 \pm 2.8) \times 10^6$	$(1.16 \pm 0.12 \pm 0.19) \pm 0.28 \times 10^{-3}$	2012
$\eta_c \longrightarrow \Sigma^+\overline{\Sigma}^-$ [24]	2.25×10^8	$(2.11 \pm 0.28 \pm 0.18 \pm 0.5) \times 10^{-3}$	2013
$\eta_c \longrightarrow \Xi^-\overline{\Xi}^+$[24]	2.25×10^8	$(0.89 \pm 0.16 \pm 0.08 \pm 0.21) \times 10^{-3}$	

Table 3 (d). Strangeness Conserving Decays of χ_{cJ} Studied at BESIII

Decay Channel	No. of Events	Branching Fraction	year
$\chi_{c0} \longrightarrow \mathrm{P}\overline{\mathrm{P}}\,\mathrm{K}^+\mathrm{K}^-$	106×10^6	$(1.24 \pm 0.20 \pm 0.18) \times 10^{-4}$	2011
$\chi_{c1} \longrightarrow \mathrm{P}\overline{\mathrm{P}}\,\mathrm{K}^+\mathrm{K}^-$	106×10^6	$(1.35 \pm 0.15 \pm 0.19) \times 10^{-4}$	
$\chi_{c2} \longrightarrow \mathrm{P}\overline{\mathrm{P}}\,\mathrm{K}^+\mathrm{K}^-$[25]	106×10^6	$(2.08 \pm 0.19 \pm 0.30) \times 10^{-4}$	
$\chi_{c0} \longrightarrow \Lambda\overline{\Lambda}\pi^+\pi^-$	106×10^6	$(119.0 \pm 6.4 \pm 11.4)$	2012
$\chi_{c1} \longrightarrow \Lambda\overline{\Lambda}\pi^+\pi^-$		$(31.1 \pm 3.4 \pm 3.9)$	
$\chi_{c2} \longrightarrow \Lambda\overline{\Lambda}\pi^+\pi^-$[26]		$(137.0 \pm 7.6 \pm 15.7)$	
$\chi_{c0} \longrightarrow \Lambda\bar{\Lambda}$	1.06×10^8	$(33.3 \pm 2.0 \pm 2.6) \times 10^{-5}$	2013
$\chi_{c1} \longrightarrow \Lambda\bar{\Lambda}$		$(12.2 \pm 1.1 \pm 1.1) \times 10^{-5}$	
$\chi_{c2} \longrightarrow \Lambda\bar{\Lambda}$		$(20.8 \pm 1.6 \pm 2.3) \times 10^{-5}$	
$\chi_{c0} \longrightarrow \Sigma^0\overline{\Sigma}^0$		$(47.8 \pm 3.4 \pm 3.9) \times 10^{-5}$	
$\chi_{c1} \longrightarrow \Sigma^0\overline{\Sigma}^0$		$(3.8 \pm 1.0 \pm 0.5) \times 10^{-5}$	
$\chi_{c2} \longrightarrow \Sigma^0\overline{\Sigma}^0$		$(4.0 \pm 1.1 \pm 0.5) \times 10^{-5}$	
$\chi_{c0} \longrightarrow \Sigma^+\overline{\Sigma}^-$		$(45.4 \pm 4.2 \pm 3.0) \times 10^{-5}$	
$\chi_{c1} \longrightarrow \Sigma^+\overline{\Sigma}^-$		$(5.4 \pm 1.5 \pm 0.5) \times 10^{-5}$	
$\chi_{c2} \longrightarrow \Sigma^+\overline{\Sigma}^-$[27]		$(4.9 \pm 1.9 \pm 0.7) \times 10^{-5}$	
$\chi_{c0} \longrightarrow \bar{P}K^+\Lambda + c.c$	1.06×10^8	$(13.2 \pm 0.3 \pm 1.0) \times 10^{-4}$	2013
$\chi_{c1} \longrightarrow PK^+\Lambda + c.c$	1.06×10^8	$(4.5 \pm 0.2 \pm 0.4) \times 10^{-4}$	
$\chi_{c2} \longrightarrow \bar{P}K^+\Lambda + c.c$[18]	1.06×10^8	$(8.4 \pm 0.3 \pm 0.6) \times 10^{-4}$	
$\chi_{c0} \longrightarrow \Sigma^+\overline{\Sigma}^-$	$(448.1 \pm 2.9) \times 10^6$	$50.4 \pm 2.5 \pm 2.7$	2017
$\chi_{c1} \longrightarrow \Sigma^+\overline{\Sigma}^-$		$3.7 \pm 0.6 \pm 0.2$	
$\chi_{c2} \longrightarrow \Sigma^+\overline{\Sigma}^-$		$3.5 \pm 0.7 \pm 0.3$	
$\chi_{c0} \longrightarrow \Sigma^0\overline{\Sigma}^0$		$47.7 \pm 1.8 \pm 3.5$	
$\chi_{c1} \longrightarrow \Sigma^0\overline{\Sigma}^0$		$4.3 \pm 0.5 \pm 0.3$	
$\chi_{c2} \longrightarrow \Sigma^0\overline{\Sigma}^0$[28]		$3.9 \pm 0.5 \pm 0.3$	

Table 4 (a). Strangeness Violating Decays of J/ψ Studied at BESIII

Decay Channel	Branching Fraction	year
$J/\psi \longrightarrow D_S^-\rho^+$	$< 1.3 \times 10^{-5}$ at C.L 90%	2014
$J/\psi \longrightarrow \bar{D}^0\bar{K}^{*0}$[29]	$< 2.5 \times 10^{-6}$ at C.L 90%	
$J/\psi \longrightarrow \mathrm{K_S K_L}$	$(1.13 \pm 0.03 \pm 0.05)\% \times 10^{-4}$	2017
$J/\psi \longrightarrow \mathrm{K_S K_S}$[30]	$< 1.4 \times 10^{-8}$ at 95% C.L	

Table 4 (b). Strangeness Violating Decays of ψ' Studied at BESIII

Decay Channel	Branching Fraction	year
$\psi(3686) \longrightarrow K_S^0 K^{\pm}\pi^{\mp}\pi^+\pi^-$ [31]	$(7.03 \pm 2.10 \pm 0.70) \times 10^{-6}$	2013
$\psi(3686) \longrightarrow K^- \Lambda \Xi^+ + \text{c.c}$ [32]	$(3.86 \pm 0.27 \pm 0.32) \times 10^{-5}$	2015

Table 4(c). Strangeness Violating Decays of D-meson Studied at BESIII

Decay Channel	Branching Fraction	year
$D^+ \longrightarrow K_L^0 e^+ \nu_e$[33]	$(4.481 \pm 0.027 \pm 0.103)\%$	2015
$D^+ \longrightarrow K^- \pi^+ e^+ \nu_e$[34]	$(3.77 \pm 0.03 \pm 0.08)$	2016
$D^+ \longrightarrow \overline{K}^0 \mu^+ \nu_\mu$[35]	$(8.72 \pm 0.07 \pm 0.18)\%$	2016
$D_S^+ \longrightarrow \eta e^+ \nu_e$ $D_S^+ \longrightarrow \eta' e^+ \nu_e$[36]	$(2.30 \pm 0.31 \pm 0.08)\%$ $(0.93 \pm 0.30 \pm 0.05)\%$	2016
$D^+ \longrightarrow K_S^0 K_S^0 K^+$ $D^+ \longrightarrow K_S^0 K_S^0 \pi^+$ $D^0 \longrightarrow K_S^0 K_S^0$ $D^0 \longrightarrow K_S^0 K_S^0 K_S^0$[37]	$(2.54 \pm 0.05 \pm 0.12) \times 10^{-3}$ $(2.70 \pm 0.05 \pm 0.12) \times 10^{-3}$ $(1.67 \pm 0.11 \pm 0.11) \times 10^{-4}$ $(7.21 \pm 0.33 \pm 0.44) \times 10^{-4}$	2016
$D^+ \longrightarrow \overline{K}^0 e^+ \nu_e$[38]	$(8.60 \pm 0.06 \pm 0.15) \times 10^{-2}$	2017
$D_S^+ \longrightarrow \phi e^+ \nu_e$ $D_S^+ \longrightarrow \phi \mu^+ \nu_\mu$ $D_S^+ \longrightarrow \eta \mu^+ \nu_\mu$ $D_S^+ \longrightarrow \eta' \mu^+ \nu_\mu$[39]	$(2.26 \pm 0.45 \pm 0.09)\%$ $(1.94 \pm 0.53 \pm 0.09)\%$ $(2.42 \pm 0.46 \pm 0.11)\%$ $(1.06 \pm 0.54 \pm 0.07)\%$	2017

Table 4 (d). Strangeness Violating Decays of Λ_c Studied at BESIII

Decay Channel	Branching Fraction	year
$\Lambda_c^+ \longrightarrow \Lambda e^+ \nu_e$[40]	$(3.63 \pm 0.38 \pm 0.20)\%$	2015
$\Lambda_c^+ \longrightarrow P K^- \pi^+$[41]	$(5.84 \pm 0.27 \pm 0.23)\%$	2016
$\Lambda_c^+ \longrightarrow \Sigma^- \pi^+ \pi^- \pi^0$[42]	$(2.11 \pm 0.33 \pm 0.14)\%$	2017
$\Lambda_c^+ \longrightarrow n K_S^0 \pi^+$[43]	$(1.82 \pm 0.23 \pm 0.11)\%$	2017

Table 4 (e). Strangeness Violating Decays of χ_{cJ} Studied at BESIII

Decay Channel	Branching Fraction	year
$\chi_{c0} \longrightarrow K_S^0 K^{\pm} \pi^{\mp} \pi^0$	½ × $(2.52 \pm 0.34) \times 10^{-2}$	2013
$\chi_{c1} \longrightarrow K_S^0 K^{\pm} \pi^{\mp} \pi^0$	½ × $(9.0 \pm 1.5) \times 10^{-3}$	
$\chi_{c2} \longrightarrow K_S^0 K^{\pm} \pi^{\mp} \pi^0$[44]	½ × $(1.51 \pm 0.22) \times 10^{-2}$	

Recently, it was observed that when J/ψ decays into neutral strange meson pairs such as K_SK_L and K_SK_S, strangeness always violate as given in Table 4(a) [29-30]. In Table 4(b), 3-body and 7-body strangeness violating decays are presented alongwith their branching fractions [31-32]. The table 4(c) contains higher state of charmonia named as D-meson. In years 2016 and 2017, a lot of work has been done on the D-meson decays and these are all strangeness violating because D meson is the lightest meson with mass 1.864 GeV/c^2 having single charm quark. It is necessary for the decay of D meson, one of its charm quark transform into some other quark. This transformation occurs via weak interaction and this decay is always mediated by W boson [33-39]. The 3-body and 4-body decay modes of Λ_c, given in Table 4(d) shows the strangeness violating decay modes [40-43]. In Table 4(e), the strangeness violating decays of χ_{cJ} are shown and their branching fractions are also mentioned [44]. From this study of strangeness violating decays, it can be concluded that associated production doesn't take place in strangeness violating decays and these decays corresponds to the weak interactions.

8. SUMMARY

This was a review of experimental results of BES-III experiment for studying significance of strangeness conservation-violation results of hadrons. Although no final explanation have been given in experimental results and theoretical exertions, but some positive concepts have been introduced. A detailed list of strange mesons and baryons is given along with their quark contents and strangeness values. Strangeness conserving and strangeness violating decay modes of J/ψ, ψ′, η_c, $\eta_c{}'$, $\chi_{c0,c1,c2}$, h_c and D-mesons have been presented in tabular form with proper details of number of events, Branching Fractions and the year in which that specific phenomenon was observed. The understanding of such kinds of complex decay modes is very important for the scientists to learn about the universe at its most fundamental level. Experimental and theoretical results shed light on new phenomenology and may explore new worlds in High Energy Physics, although systematic efforts are difficult to carry out for charmonium systems. This study concludes that experimental trials will be more effective rather than comparing theoretical perceptions. Although, we may not reach up to revolutionary ideas of existing impressions but from any struggle, a new episode of experimental High Energy physics may be released from studying "significance of strangeness conservation-violation decays of strange mesons".

9. ACKNOWLEDGEMENTS

We pay our gratitude to Higher Education Commission of Pakistan for their financial support under Indigenous PhD Fellowship Program, Phase VI. We are highly indebted to Prof. Dr. Haris Rashid, Dr. Talab Hussain and Dr. Abrar Ahmad Zafar for their valuable guidance and moral support.

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