$SU(3)_{\text{flavor}}$ analysis of two-body weak decays of charmed baryons

K. K. Sharma and R. C. Verma
Centre for Advanced Study in Physics, Department of Physics, Panjab University, Chandigarh -160014 India

ABSTRACT

We study two-body weak decays of charmed baryons $\Lambda_c^+$, $\Xi_c^+$ and $\Xi_c^0$ into an octet or decuplet baryon and a pseudoscalar meson employing the $SU(3)$ flavor symmetry. Using certain measured Cabibbo-favored modes, we fix the reduced amplitudes and predict the branching ratios of various decays of charmed baryons in the Cabibbo-enhanced, -suppressed and -doubly suppressed modes.

PACS numbers(s): 13.30.Eg, 11.30.Hv, 11.40.Ha, 14.20.Lq

1Present address: Department of Physics, Punjabi University, Patiala-147 002, India
I. INTRODUCTION

As more new data [1-4] on charmed baryons become available in recent years, the theoretical study of nonleptonic weak decays of charmed baryons has acquired significance. Earlier, it was hoped that like meson decays the spectator quark process would dominate for charm baryon decays also. However, this scheme does not seem to be supported by experiment, as the observed branching ratio for decays like $\Lambda_c^+ \rightarrow \Sigma^+ \pi^0/\Xi^0 K^+$, forbidden in the spectator quark model, are significantly large thereby indicating the need of non-spectator contributions. Generally, these contributions are treated through the current algebra approach and soft pion techniques [5]. Unfortunately, the calculations of both pole terms and factorizable contributions have their own uncertainties associated with many parameters and even by adjusting all the parameters, agreement with the experimental observations is far from satisfactory [6].

An alternative to the above approach is to employ flavor symmetry approach [7-9]. Though, this approach involves a number of unknown reduced amplitudes, it has the advantage that it lumps all the dynamical processes together. In contrast to the badly broken $SU(4)$ charm scheme, $SU(3)$ flavor symmetry is expected to be more reliable for the study of charm baryons. Recently, one of us (RCV) and Khanna [10] have studied the Cabibbo-favored ($CF$) decays of charmed baryons in the $SU(3)$ flavor symmetry generated by u, d and s quarks. In this work, we extend this approach to study Cabibbo-suppressed ($CS$) and -doubly-suppressed ($CDS$) $B_c \rightarrow BP/DP$ decays (where $B_c$ represents the charmed baryon and $B/D$ the octet/decuplet baryon and $P$ a pseudoscalar meson respectively). Using the data available on $\Lambda_c^+ \rightarrow \Lambda \pi^+/\Sigma^+ \pi^0/\Xi^0 K^+$ decays, we determine the reduced amplitudes, which are then used to predict branching ratios and asymmetry of various CF, CS and CDS decays. Similarly, we also study $B_c \rightarrow DP$ decays, where we use $Br(\Lambda_c^+ \rightarrow \Delta^{++} K^-/\Xi^{*0} K^+)$ to fix the reduced amplitudes.

II. THEORETICAL FRAMEWORK

Structure of the general weak current $\otimes$ current Hamiltonian $H_w$ including short distance $QCD$ effects for the charm changing Cabibbo-favored decays ($\Delta C = \Delta S = -1$)
where \( G_F = \frac{G_F}{\sqrt{2}} V_{td} V_{ts}^* \) and \( \bar{q}_1 q_2 \equiv \bar{q}_1 \gamma \mu (1 - \gamma_5) q_2 \) represents color singlet \( V - A \) current and the QCD coefficients at the charm mass scale are

\[
c_1 = 1.26 \pm 0.04, \quad c_2 = -0.51 \pm 0.05. \tag{2}
\]

The effective weak Hamiltonian (1) transforms as an admixture of the 6* and 15 representations of the \( SU(3) \)-flavor, which can be expressed as

\[
H_W^{6*} = \sqrt{2} g_{8s} \left\{ \bar{B}_m^a P_m^m B^h_{[n,a]} + \bar{B}_b^m P_m^m B^n_{[n,a]} \right\} \\
+ \sqrt{2} g_{8a} \left\{ \bar{B}_m^a P_m^m B^n_{[n,a]} - \bar{B}_b^m P_m^m B^n_{[n,a]} \right\} \\
+ \frac{\sqrt{2}}{2} g_{10} \left\{ \bar{B}_b^a P_c^c B^h_{[a,c]} + \bar{B}_b^c P_d^d B^h_{[a,c]} \\
- \frac{1}{3} \bar{B}_b^a P_c^c B^n_{[n,a]} + \frac{1}{3} \bar{B}_b^a P_d^d B^n_{[n,a]} \right\}, \tag{3}
\]

\[
H_W^{15} = \frac{\sqrt{2}}{2} h_{27} \left\{ \bar{B}_m^a P_m^m B^h_{(a,c)} + \bar{B}_b^a P_m^m B^n_{(a,c)} \right\} \\
- \frac{1}{5} \bar{B}_b^a P_c^c B^n_{(n,c)} - \frac{1}{5} \bar{B}_b^a P_d^d B^n_{(n,c)} \\
+ \frac{\sqrt{2}}{2} h_{10} \left\{ \bar{B}_b^a P_c^c B^h_{(a,c)} - \bar{B}_b^c P_d^d B^h_{(a,c)} \\
+ \frac{1}{3} \bar{B}_b^a P_c^c B^n_{(n,c)} - \frac{1}{3} \bar{B}_b^a P_d^d B^n_{(n,c)} \right\} \\
+ \sqrt{2} h_{8s} \left\{ \bar{B}_m^m P_b^m B^h_{(n,a)} + \bar{B}_b^m P_m^m B^n_{(n,a)} \right\} \\
+ \sqrt{2} h_{8a} \left\{ \bar{B}_m^m P_b^m B^n_{(n,a)} - \bar{B}_b^m P_m^m B^n_{(n,a)} \right\}, \tag{4}
\]

where the QCD coefficients \( c_1 \) and \( c_2 \) get absorbed in the reduced amplitudes \( g \)'s and \( h \)'s. Here, \( B^a \equiv (-\Xi^0, \Xi^+_c, \Lambda^+_c) \), and \( B^a_6 \) denote the antitriplet of charmed baryons and octet baryons respectively. \( P^a_6 \) denotes 3 \( \times \) 3 matrix of the uncharmed pseudoscalar meson nonet

\[
P^a_6 = \begin{pmatrix} \pi^- & P^2_2 & K^0 \\ \pi^+ & P^2_1 & K^+ \\ K^- & K^0 & P^3_3 \end{pmatrix}, \tag{5}
\]

with

\[
P^1_1 = \frac{1}{\sqrt{2}} \{ \pi^0 + \eta \sin \theta + \eta' \cos \theta \},
\]
\[ P_2^2 = \frac{1}{\sqrt{2}} \{- \pi^0 + \eta \sin \theta + \eta' \cos \theta \}, \]
\[ P_3^3 = \{- \eta \cos \theta + \eta' \sin \theta \}, \] (6)

where \( \theta \) governs the \( \eta - \eta' \) mixing and is related to the physical mixing as

\[ \theta = \theta_{\text{ideal}} - \phi_{\text{phy}}. \] (7)

The amplitude for the decay process \( B_c \to BP \) is defined by

\[ < B_f P | H_W | B_i > = i\bar{u}_{B_f} \{ A - \gamma_5 B \} u_{B_i} \phi_p, \] (8)

where \( A \) and \( B \) are respectively \( s \)-wave and \( p \)-wave amplitudes and \( u_B \) are the Dirac spinors. This gives the decay rate

\[ \Gamma(B_i \to B_f + P) = C_1 \{|A|^2 + C_2 |B|^2\}, \] (9)

and asymmetry parameter

\[ \alpha = \frac{2 \text{ Re}(A\bar{B}^*)}{(|A|^2 + |B|^2)}, \] (10)

with \( \bar{B} = \sqrt{C_2}B \). The kinematical factors \( C_1, C_2 \) are given by

\[ C_1 = \frac{|p_c| (m_i + m_f)^2 - m_p^2}{8\pi m_i^2}, \] (11)
\[ C_2 = \frac{(m_i - m_f)^2 - m_p^2}{(m_i + m_f)^2 + m_p^2}. \] (12)

where \( p_c \) is the center of mass three-momentum in the rest frame of the parent particle. \( m_i, m_f \) are masses of initial and final state baryons respectively and \( m_p \) is the mass of the meson emitted.

**III. NUMERICAL CALCULATIONS AND RESULTS**

**A. Cabibbo-favored mode**

To illustrate the procedure, we discuss the main steps involved in the determination of the reduced amplitudes. Taking \( H_{13}^2 \) component of the weak Hamiltonian in (3) and (4), the decay amplitudes of various Cabibbo-favored decays of antitriplet charmed baryons are obtained [7, 8, 10]. There are seven reduced amplitudes in each of the \( PV \) and \( PC \) modes. Assuming \( 6^* \) dominance of the weak Hamiltonian, we reduce the number of unknown parameters from seven to three in each of these modes.
A recent CLEO measurement [3] has reported the following set of $PV$ and $PC$ amplitudes (in the units of $G_F V_{ud} V_{cs}^* \times 10^{-2} GeV^2$)

$$A(\Lambda_c^+ \rightarrow \Lambda \pi^+) = -3.0^{+0.8}_{-1.2} \text{ or } -4.3^{+0.8}_{-0.9},$$

$$B(\Lambda_c^+ \rightarrow \Lambda \pi^+) = +12.7^{+2.7}_{-2.5} \text{ or } +8.9^{+3.4}_{-2.4},$$

$$A(\Lambda_c^+ \rightarrow \Sigma^+ \pi^0) = +1.3^{+0.9}_{-1.1} \text{ or } +5.4^{+0.9}_{-0.7},$$

$$B(\Lambda_c^+ \rightarrow \Sigma^+ \pi^0) = -17.3^{+2.3}_{-2.9} \text{ or } -4.1^{+3.4}_{-3.0}. \quad (13)$$

It has been shown [10] that the present data on $Br(\Lambda_c^+ \rightarrow p\bar{K}^0)$ prefers the following set:

$$A(\Lambda_c^+ \rightarrow \Lambda \pi^+) = -3.0^{+0.8}_{-1.2}, \quad B(\Lambda_c^+ \rightarrow \Lambda \pi^+) = +12.7^{+2.7}_{-2.5},$$

$$A(\Lambda_c^+ \rightarrow \Sigma^+ \pi^0) = +5.4^{+0.9}_{-0.7}, \quad B(\Lambda_c^+ \rightarrow \Sigma^+ \pi^0) = -4.1^{+3.4}_{-3.0}. \quad (14)$$

Further, experimental branching ratio $Br(\Lambda_c^+ \rightarrow \Xi^0 K^+) = (0.34 \pm 0.09)\% \ [9]$ yields,

$$|A(\Lambda_c^+ \rightarrow \Xi^0 K^+)|^2 + C_2 |B(\Lambda_c^+ \rightarrow \Xi^0 K^+)|^2 = 14.42 \pm 3.82. \quad (15)$$

Various dynamical mechanisms considered for the charm baryon decays indicate that the $PV$ mode of this decay is highly suppressed. This decay in $PV$ mode can neither occur through the spectator quark scheme nor from the equal time commutator (ETC) term of the current algebra. Even through the $(\frac{1}{2}^-)_b$ baryon pole, it acquires a negligibly small contribution [11]. Therefore, taking $\alpha(\Lambda_c^+ \rightarrow \Xi^0 K^+) \approx 0$, we fix

$$|B(\Lambda_c^+ \rightarrow \Xi^0 K^+)| = \pm (16.52 \pm 2.19). \quad (16)$$

Using the decay amplitudes of $\Lambda_c^+ \rightarrow \Lambda \pi^+ / \Sigma^+ \pi^0 / \Xi^0 K^+$, we express the reduced amplitudes as follows:

$$g_{8s} = \frac{1}{2} \left\{ \frac{1}{\sqrt{2}} < \Sigma^+ \pi^0 | \Lambda_c^+ > - \sqrt{3} < \Lambda \pi^+ | \Lambda_c^+ > - < \Xi^0 K^+ | \Lambda_c^+ > \right\}, \quad (17)$$

$$g_{8A} = \frac{1}{6} \left\{ \frac{5}{\sqrt{2}} < \Sigma^+ \pi^0 | \Lambda_c^+ > - \sqrt{3} < \Lambda \pi^+ | \Lambda_c^+ > + < \Xi^0 K^+ | \Lambda_c^+ > \right\}, \quad (18)$$

$$g_{10} = \left\{ \frac{1}{\sqrt{2}} < \Sigma^+ \pi^0 | \Lambda_c^+ > + \sqrt{3} < \Lambda \pi^+ | \Lambda_c^+ > - < \Xi^0 K^+ | \Lambda_c^+ > \right\}. \quad (19)$$
which can be used to determine the other decays. For instance, $\Lambda_c^+ \to p\bar{K}^0$ decay amplitude is expressed as:

$$< p\bar{K}^0 | \Lambda_c^+ > = \frac{1}{\sqrt{2}} \{ \sqrt{3} < \Lambda \pi^+ | \Lambda_c^+ > - < \Sigma^+ \pi^0 | \Lambda_c^+ > \},$$

where the error is calculated using the average of errors given in (14). Thus we calculate

$$Br(\Lambda_c^+ \to p\bar{K}^0) = (2.67 \pm 0.74)\%,$$

and

$$\alpha = -0.99 \pm 0.39,$$

which agrees with the observed experimental branching ratio of $(2.1 \pm 0.4)\%$ [1]. Following this procedure, we determine branching ratio and asymmetry of remaining Cabibbo-enhanced decays taking negative and positive signs of $B(\Lambda_c^+ \to \Xi^0 K^+)$. For $\Lambda_c \to \Sigma \pi$ decays, isospin symmetry yields:

$$Br(\Lambda_c^+ \to \Sigma^0 \pi^+) = Br(\Lambda_c^+ \to \Sigma^+ \pi^0),$$

$$(0.87 \pm 0.20)\% = (0.87 \pm 0.22)\% \quad (Expt.)$$

which holds well, and

$$\alpha(\Lambda_c^+ \to \Sigma^0 \pi^+) = \alpha(\Lambda_c^+ \to \Sigma^+ \pi^0) = (-0.45 \pm 0.31 \pm 0.06).$$

For $\Lambda_c^+ \to \Sigma^+ \eta$, we obtain

$$Br(\Lambda_c^+ \to \Sigma^+ \eta) = (0.50 \pm 0.17)\%, \text{ at } \phi_{phy} = -10^0,$$

$$= (0.55 \pm 0.19)\%, \text{ at } \phi_{phy} = -19^0,$$

with the negative sign of $B(\Lambda_c^+ \to \Xi^0 K^+)$, and

$$Br(\Lambda_c^+ \to \Sigma^+ \eta) = (0.97 \pm 0.23)\%, \text{ at } \phi_{phy} = -10^0,$$

$$= (1.23 \pm 0.28)\%, \text{ at } \phi_{phy} = -19^0,$$
with the positive sign. A recent CLEO measurement [2]

\[
\frac{Br(\Lambda_c^+ \to \Sigma^+ \eta)}{Br(\Lambda_c^+ \to pK^- \pi^+)} = 0.11 \pm 0.03 \pm 0.02,
\]

(27)

combined with \(Br(\Lambda_c^+ \to pK^- \pi^+) = 4.4 \pm 0.6\%\) [1] yields

\[
Br(\Lambda_c^+ \to \Sigma^+ \eta) = 0.48 \pm 0.17,
\]

(28)

which seems to prefer the negative sign of \(B(\Lambda_c^+ \to \Xi^0 K^+).\) Recently, branching ratio of \(\Xi^0 \to \Xi^0 \pi^+\) has also been measured in a CLEO-II experiment [4] to be \((1.2 \pm 0.5 \pm 0.3)\%\). For this mode we obtain values \((4.14 \pm 1.27)\%\) and \((0.07 \pm 0.02)\%\) for negative and positive signs of \(B(\Lambda_c^+ \to \Xi^0 K^+).\) respectively. Thus experiment seems to prefer the positive sign. Therefore, in Tables I(a) and I(b), we give branching ratios of CF decays for both the signs, for the sake of comparison. The decays \(\Xi^0 \to \Lambda \bar{K}^0 / \Sigma^0 \bar{K}^0 / \Xi^- \pi^+\) remain unaffected by the sign of \(B(\Lambda_c^+ \to \Xi^0 K^+).\)

B. Cabibbo-suppressed mode

Effective weak Hamiltonian for these decays \((\Delta C = -1, \Delta S = 0)\) is given by

\[
H_w = \tilde{G}_F \left[ c_1 \{ (\bar{u}d)(\bar{d}c) - (\bar{s}u)(\bar{s}c) \} + c_2 \{ (\bar{d}d)(\bar{u}c) - (\bar{s}s)(\bar{u}c) \} \right],
\]

(29)

where \(\tilde{G}_F = \frac{-G_F}{\sqrt{2}} V_{ud} V_{cd}^*\) and other quantities have the usual meanings. Choosing \((H_{12}^2 - H_{13}^3)\) components of the weak Hamiltonian in (3) and (4), decay amplitudes for various Cabibbo-suppressed decays are obtained [7, 8]. As the same reduced amplitudes appear here, the CS decay amplitudes can be expressed in terms of those of the CF modes.

In the following, we obtain some of these relations using 6* dominance of \(H_w.\)

\[
-tan\theta_c < \Xi^0 K^+ |\Lambda_c^+ > = - < pK^- |\Xi^0 c > = < \Sigma^+ \pi^- |\Xi^0 c > ,
\]

(30)

\[
\sqrt{2} tan\theta_c < \Sigma^+ \pi^0 |\Lambda_c^+ > = - < n\bar{K}^0 |\Xi^0 c > = < \Xi^0 K^0 |\Xi^0 c > ,
\]

(31)

\[
-tan\theta_c \{ \frac{\sqrt{3}}{2} < \Lambda \pi^+ |\Lambda_c^+ > - \frac{1}{\sqrt{2}} < \Sigma^+ \pi^0 |\Lambda_c^+ > \} = < \Sigma^- \pi^- |\Xi^0 c >
\]

(32)

\[
-tan\theta_c \{ \frac{1}{\sqrt{2}} < \Sigma^+ \pi^0 |\Lambda_c^+ > + \frac{\sqrt{3}}{2} < \Lambda \pi^+ |\Lambda_c^+ > \} = -\sqrt{2} < p\pi^0 |\Lambda_c^+ >
\]
\[ = - n\pi^+|\Lambda^+_c > = < \Xi^0 K^+|\Xi^+_c >, \quad (33) \]

\[-\tan\theta_c \{-\sqrt{2} < \Sigma^+\pi^0|\Lambda^+_c > + < \Xi^0 K^+|\Lambda^+_c > \} = - \sqrt{2} < \Sigma^0 K^+|\Lambda^+_c > \]

\[ = - < \Sigma^+ K^0|\Lambda^+_c > = < p\bar{K}^0|\Xi^+_c >, \quad (34) \]

\[-\tan\theta_c \{ < \Xi^0 K^+|\Lambda^+_c > - \frac{2}{3} < \Lambda\pi^+|\Lambda^+_c > \} = \sqrt{\frac{2}{3}} < \Lambda K^+|\Lambda^+_c >, \quad (35) \]

\[-\tan\theta_c \{ \frac{3}{2} < \Lambda\pi^+|\Lambda^+_c > - \frac{1}{\sqrt{2}} < \Sigma^+\pi^0|\Lambda^+_c > + < \Xi^0 K^+|\Lambda^+_c > \} = 2 < \Sigma^0\pi^0|\Xi^+_c >, \quad (36) \]

\[-\tan\theta_c \{ - < \Xi^0 K^+|\Lambda^+_c > + \sqrt{\frac{3}{2}} < \Lambda\pi^+|\Lambda^+_c > - \frac{1}{\sqrt{2}} < \Sigma^+\pi^0|\Lambda^+_c > \} = \sqrt{\frac{2}{3}} < \Sigma^0\pi^0|\Xi^+_c > = - \sqrt{2} < \Sigma^+\pi^0|\Xi^+_c >, \quad (37) \]

\[-\tan\theta_c \{ 3 < \Xi^0 K^+|\Lambda^+_c > - \sqrt{\frac{3}{2}} < \Lambda\pi^+|\Lambda^+_c > - \frac{3}{\sqrt{2}} < \Sigma^+\pi^0|\Lambda^+_c > \} = \sqrt{6} < \Lambda\pi^+|\Xi^+_c > = - \sqrt{12} < \Lambda\pi^0|\Xi^+_c >, \quad (38) \]

We give the decay asymmetries and branching ratios for the CS decays, in Tables II(a) and II(b) for both the signs of \( B(\Lambda^+_c \to \Xi^0 K^+) \). In the present analysis, we find that the decays \( \Xi^+_c \to p\bar{K}^0/\Lambda\pi^+ \) and \( \Xi^0_c \to \Sigma^-\pi^+/\Xi^- K^+ \) are dominant for both choices. Among the \( \Lambda^+_c \) decays, \( \Lambda^+_c \to \Lambda K^+/p\eta \) and \( \Lambda^+_c \to \Sigma^+ K^0 \) are dominant for negative and positive signs of \( B(\Lambda^+_c \to \Xi^0 K^+) \) respectively.

**C. Cabibbo-doubly-suppressed mode**

For the Cabibbo-doubly-suppressed decays \( \Delta C = -\Delta S = -1 \) the effective weak Hamiltonian is

\[ H_w = \tilde{G}_F^n [c_1(\bar{u}s)(\bar{d}c) + c_2(\bar{d}s)(\bar{u}c)], \quad (39) \]

where \( \tilde{G}_F^n = - \frac{G_F}{\sqrt{2}} V_{us} V_{cd}^* \). Here also the CDS decays can be expressed in term of the CF modes. Using 6\(^*\) dominance of the weak Hamiltonian, we obtain the following decay amplitude relations:

\[-\tan^2\theta_c < \Xi^0 K^+|\Lambda^+_c > = \sqrt{2} < p\pi^0|\Xi^+_c > = < n\pi^+|\Xi^+_c > \]

\[ = - \sqrt{2} < n\pi^0|\Xi^0_c > = < p\pi^-|\Xi^+_c >, \quad (40) \]

\[-\tan^2\theta_c \{ \frac{3}{2} < \Lambda\pi^+|\Lambda^+_c > - \frac{1}{\sqrt{2}} < \Sigma^+\pi^0|\Lambda^+_c > \} = \sqrt{2} < \Sigma^0 K^+|\Xi^+_c > \]
\[ = \langle \Sigma^+ K^0 | \Xi^+_c \rangle = \langle \Sigma^- K^- | \Xi^0_c \rangle = -\sqrt{2} \langle \Sigma^0 K^0 | \Xi^0_c \rangle, \quad (41) \]

\[ -\tan^2 \theta_c \{- \frac{3}{\sqrt{2}} \langle \Sigma^+ \pi^0 | \Lambda_c^+ \rangle - \sqrt{\frac{3}{2}} \langle \Lambda \pi^+ | \Lambda_c^+ \rangle \} = \sqrt{6} \langle \Lambda K^+ | \Xi^+_c \rangle \]

\[ = \sqrt{6} \langle \Lambda K^0 | \Xi^0_c \rangle, \quad (42) \]

\[ -\tan^2 \theta_c \{- \sqrt{\frac{3}{2}} \langle \Lambda \pi^+ | \Lambda_c^+ \rangle - \frac{1}{\sqrt{2}} \langle \Sigma^+ \pi^0 | \Lambda_c^+ \rangle + \langle \Xi^0 K^+ | \Lambda_c^+ \rangle \} \]

\[ = -\langle pK^0 | \Lambda_c^+ \rangle = \langle nK^+ | \Lambda_c^+ \rangle. \quad (43) \]

Calculated asymmetries and branching ratios of the CDS decays are given in the Tables III(a) and III(b). Among \( \Xi_c \) decays, \( \Xi_c^+ \rightarrow \Sigma^+ K^0/\Sigma^0 K^+/n \pi^+/p \pi^0 \) and \( \Xi_c^0 \rightarrow \Sigma^- K^+ \) are found to be dominant modes for positive as well as negative choice of \( B(\Lambda_c^+ \rightarrow \Xi^0 K^+) \).

However, branching ratios of \( \Lambda_c^+ \) decays show drastic difference between the two choices, even their decay asymmetries also acquire different signs.
### IV. $B_c(1/2)^+ \rightarrow D(3/2)^+ + P(0^-)$ Decays

The matrix element for the baryon $(1/2)^+ \rightarrow (3/2)^+ + 0^-$ decay process is

$$M = <D, P|H_w|B_c> = iP_\mu \bar{w}^\mu_D (C - \gamma_5 D) u_{B_c} \phi_P,$$

where $P_\mu$ is the four momentum of the meson and $w^\mu$ is the Rarita-Schwinger spinor for a spin $3/2^+$ particle. $C$ and $D$ denote the $p-$wave and $d-$wave amplitudes respectively. The decay rate and asymmetry parameter are computed from

$$\Gamma(B_i \rightarrow B_f + P) = \frac{|p_c|^3 m_i (m_f + E_f)}{6\pi m_f^2} \{|C|^2 + |\bar{D}|^2\},$$

$$\alpha = \frac{2 \text{ Re}(C \bar{D}^*)}{(|C|^2 + |\bar{D}|^2)},$$

where $\bar{D}$ is defined as

$$\bar{D} = \rho D, \quad \rho = \left\{ \frac{E_f - m_f}{E_f + m_f} \right\}^{1/2}.$$ 

$E_f$ is the energy of the final state baryon in the rest frame of $B_c$ and other quantities have the usual meaning. The weak Hamiltonian for decuplet baryon emitting decays is given by

$$H^6_W = \sqrt{2} j_8 \{ \epsilon_{mbd} D^{mnec} P_n^d B^a H^b_{[a,c]} \},$$

$$H^{15}_W = \sqrt{2} k_8 \{ \epsilon_{mpb} \bar{D}^{mnca} P_n^p B^c H^b_{(a,c)} \} + \sqrt{2} k_{10} \{ \epsilon_{mbd} \bar{D}^{mac} P_n^d B^d H^b_{(a,c)} - \epsilon_{mbd} \bar{D}^{mac} P_n^d B^d H^b_{(a,c)} + \frac{2}{3} \epsilon_{mbd} \bar{D}^{mdc} P_n^d B^a H^b_{(a,c)} \} + \sqrt{2} k_{27} \{ \epsilon_{mbd} \bar{D}^{mac} P_n^d B^d H^b_{(a,c)} + \epsilon_{mbd} \bar{D}^{mac} P_n^d B^d H^b_{(a,c)} - \frac{2}{5} \epsilon_{mbd} \bar{D}^{mdc} P_n^d B^a H^b_{(a,c)} \},$$

where $\epsilon_{abc}$ is the Levi-Civita symbol and $D_{abc}$ represents the totally symmetric decuplet baryons.

Decay amplitudes for CF, CS, and CDS modes are obtained by taking $H^6_{13}$, $(H^2_{12} - H^3_{13})$, and $H^3_{12}$ components of the weak Hamiltonian [8, 10]. Here, we have four unknown reduced amplitudes in each of the $PV$ and $PC$ modes. Dynamically, in contrast to
$B(\frac{1}{2})^+ \rightarrow B(\frac{1}{2})^+ + P(0)^-$ decays, the description of $B(\frac{1}{2})^+ \rightarrow D(\frac{3}{2})^+ + P(0)^-$ is considerably simpler. It has been shown [12] that the prime feature of these decays is that, they are factorization forbidden and arise only through W-exchange diagrams. Also Kohra [13], while performing a quark-diquark analysis, has observed that most of the quark diagrams, allowed for $(\frac{1}{2})^+ \rightarrow (\frac{1}{2})^+ + 0^-$ decays are forbidden for $(\frac{1}{2})^+ \rightarrow (\frac{3}{2})^+ + 0^-$ decays due to the symmetry property of the decuplet baryons. There exist only two independent diagrams which correspond to

$$A = d_1 \bar{D}^{1ab} B_{[2,a]} M^3_b + d_2 \bar{D}^{3ab} B_{[2,a]} M^1_b.$$  \hfill (50)

This amounts to the following constraints:

$$k_8 = \frac{1}{3} k_{10}, \quad k_{27} = 0, \quad (51)$$

for the 15-part of the weak Hamiltonian in our model. Thus, the number of unknown reduced amplitudes is reduced to two ($j_8$ and $k_8$). Generally, the W-exchange diagram contributions to the PV mode are small and it is invariably suppressed due to the centrifugal barrier for $B \rightarrow D + P$ decays. Therefore, we ignore them in the present analysis.

Experimental values [1]

$$Br(\Lambda_c^+ \rightarrow \Delta^{++}K^-) = (0.7 \pm 0.4)\%,$$  \hfill (52)

$$Br(\Lambda_c^+ \rightarrow \Xi^{0}K^+) = (0.23 \pm 0.09)\%,$$  \hfill (53)

then yields (in $G_F V_{ud} V_{cs}^* \times 10^{-2} GeV^2$)

$$k_8 = -9.10 \pm 4.15, \quad j_8 = -77.14 \pm 12.45.$$  \hfill (54)

Using these, we calculate the branching ratios, which are listed in column (ii) of Tables IV, V and VI, for Cabibbo-enhanced, -suppressed and -doubly suppressed modes respectively. In the Cabibbo-enhanced mode, $\Lambda_c^+ \rightarrow \Sigma^+\pi^0/\Sigma^0\pi^+$ and $\Xi_c^0 \rightarrow \Xi^{*-}\pi^+/\Omega^-K^+$ dominate, whereas $\Xi_c^+ \rightarrow \Sigma^{*-}\pi^+$ decays remain forbidden in the present model like other theoretical models. In the $CS$ sector, we find that the decays $\Lambda_c^+ \rightarrow \Delta^+\pi^0/\Delta^0\pi^+$, $\Xi_c^+ \rightarrow \Delta^{++}K^-/\Sigma^{*+}\pi^0/\Sigma^{0}\pi^+$ and $\Xi_c^0 \rightarrow \Sigma^{*-}\pi^+$ are dominant. In the $CDS$ mode, $\Lambda_c^+ \rightarrow \Delta^+K^0/\Delta^0K^+$ decays are forbidden, and $\Xi_c^+ \rightarrow \Delta^{++}\pi^-/\Delta^+\pi^0/\Delta^0\pi^+$, $\Xi_c^0 \rightarrow \Delta^-\pi^+/\Delta^0\pi^0$ decays are dominant. We
hope that the observation of these decays would decipher the strength of various weak
decay mechanisms, particularly of the 15-part of weak Hamiltonian.

V. Summary and discussion

The two-body weak decays of charmed baryons $\Lambda_c^+$, $\Xi_c^+$ and $\Xi_c^0$ into an octet or decouplet
baryon and a pseudoscalar meson are analysed in the framework of $SU(3)$ flavor symmetry,
for Cabibbo-enhanced, -suppressed and doubly-suppressed modes. We fix the unknown
reduced amplitudes from certain measured Cabibbo-enhanced modes and then predict
the branching ratios and asymmetries of various decays. This work was motivated by the
observation that various dynamical models used for studying these decays are far from
explaining the data on $\Lambda_c$-decays. In the flavor symmetry approach various processes
responsible for the decays are lumped together in the reduced amplitudes. However, the
results obtained here, may be affected by the $SU(3)$ symmetry breaking, as is evident
from the the charm meson decays [14] and the $\Lambda_c$, and $\Xi_c^0$ lifetimes [1]. In the present
framework, the inclusion of the $SU(3)$ symmetry breaking effects would introduce a large
number of parameters which can not be determined with the available data.
Table I(a) Branching ratios and asymmetries of CF \((B_c \rightarrow BP)\) decays for \(B(\Lambda^+ \rightarrow \Xi^0 K^+) = -16.52 \pm 2.19\)

| Decay                  | Asymmetry          | Br\%      |
|------------------------|--------------------|-----------|
| \(\Lambda^+_c \rightarrow pK^0\) | \(-0.99 \pm 0.39\) | \(2.67 \pm 0.74\) |
| \(\Lambda^+_c \rightarrow \Lambda \pi^+\) | \(-0.94 \pm 0.24^*\) | \(0.79 \pm 0.18^*\) |
| \(\Lambda^+_c \rightarrow \Sigma^+ \pi^0\) | \(-0.45 \pm 0.32^*\) | \(0.87 \pm 0.22^*\) |
| \(\Lambda^+_c \rightarrow \Sigma^+ \eta\) | \(0.92 \pm 0.47^1 (0.76 \pm 0.43^2)\) | \(0.50 \pm 0.17^1 (0.55 \pm 0.19^2)\) |
| \(\Lambda^+_c \rightarrow \Sigma^+ \eta'\) | \(-0.75 \pm 0.38^1 (-0.89 \pm 0.46^2)\) | \(0.20 \pm 0.08^1 (0.16 \pm 0.06^2)\) |
| \(\Lambda^+_c \rightarrow \Sigma^0 \pi^+\) | \(-0.45 \pm 0.32\) | \(0.87 \pm 0.20\) |
| \(\Lambda^+_c \rightarrow \Xi^0 K^+\) | \(-0.00\) | \(0.34 \pm 0.09^*\) |
| \(\Xi^+_c \rightarrow \Xi^0 \pi^+\) | \(0.03 \pm 0.31\) | \(4.14 \pm 1.27\) |
| \(\Xi^0_c \rightarrow \Sigma^+ \bar{K}^0\) | \(0.03 \pm 0.29\) | \(4.18 \pm 1.28\) |
| \(\Xi^0_c \rightarrow \Xi^0 \pi^0\) | \(0.72 \pm 0.41\) | \(0.52 \pm 0.15\) |
| \(\Xi^0_c \rightarrow \Xi^0 \eta\) | \(-0.96 \pm 0.38^1 (-0.95 \pm 0.32^2)\) | \(0.29 \pm 0.08^1 (0.37 \pm 0.08^2)\) |
| \(\Xi^0_c \rightarrow \Xi^0 \eta'\) | \(-0.63 \pm 0.40^1 (-0.60 \pm 0.48^2)\) | \(0.12 \pm 0.05^1 (0.08 \pm 0.04^2)\) |
| \(\Xi^0_c \rightarrow \Xi^- \pi^+\) | \(-0.96 \pm 0.38\) | \(1.30 \pm 0.36\) |
| \(\Xi^0_c \rightarrow \Sigma^+ K^-\) | \(-0.00\) | \(0.38 \pm 0.10\) |
| \(\Xi^0_c \rightarrow \Sigma^0 \bar{K}^0\) | \(0.07 \pm 0.67\) | \(0.11 \pm 0.07\) |
| \(\Xi^0_c \rightarrow \Lambda \bar{K}^0\) | \(-0.85 \pm 0.36\) | \(0.68 \pm 0.49\) |

*Input, \(^1\)For \(\phi_{phy} = -10^0\), \(^2\)For \(\phi_{phy} = -19^0\)
Table I(b) Branching ratios and asymmetries of CF ($B_c \rightarrow BP$) decays for $B(\Lambda_c^+ \rightarrow \Xi^0 K^+) = +16.52 \pm 2.19$

| Decay                  | Asymmetry                     | $Br\%$          |
|------------------------|-------------------------------|-----------------|
| $\Lambda_c^+ \rightarrow pK^0$ | $-0.99 \pm 0.39$             | 2.67 ± 0.74     |
| $\Lambda_c^+ \rightarrow \Lambda \pi^+$ | $-0.94 \pm 0.24^*$         | 0.79 ± 0.18*    |
| $\Lambda_c^+ \rightarrow \Sigma^+ \pi^0$ | $-0.45 \pm 0.32^*$          | 0.87 ± 0.22*    |
| $\Lambda_c^+ \rightarrow \Sigma^+ \eta$ | $-0.96 \pm 0.34^1 (-0.96 \pm 0.32^2)$ | 0.97 ± 0.23^1 (1.23 ± 0.28^2) |
| $\Lambda_c^+ \rightarrow \Sigma^+ \eta'$ | $-0.91 \pm 0.40^1 (-0.90 \pm 0.45^2)$ | 0.24 ± 0.08^1 (0.16 ± 0.06^2) |
| $\Lambda_c^+ \rightarrow \Sigma^0 \pi^+$ | $-0.45 \pm 0.32$           | 0.87 ± 0.20     |
| $\Lambda_c^+ \rightarrow \Xi^0 K^+$  | 0.00                          | 0.34 ± 0.09*    |
| $\Xi^+ \rightarrow \Xi^0 \pi^+$   | $-0.24 \pm 0.23$            | 0.07 ± 0.02     |
| $\Xi^+ \rightarrow \Sigma^+ K^0$  | $-0.23 \pm 0.22$            | 0.07 ± 0.02     |
| $\Xi_c^0 \rightarrow \Xi^0 \pi^0$ | $-0.99 \pm 0.37$            | 0.78 ± 0.20     |
| $\Xi_c^0 \rightarrow \Xi^0 \eta$  | $0.14 \pm 0.34^1 (-0.25 \pm 0.29^2)$ | 0.19 ± 0.06^1 (0.25 ± 0.07^2) |
| $\Xi_c^0 \rightarrow \Xi^0 \eta'$ | $-0.99 \pm 0.42^1 (-0.99 \pm 0.47^2)$ | 0.18 ± 0.06^1 (0.15 ± 0.05^2) |
| $\Xi_c^0 \rightarrow \Xi^- \pi^+$ | $-0.96 \pm 0.38$            | 1.30 ± 0.36     |
| $\Xi_c^0 \rightarrow \Sigma^+ K^-$ | 0.00                         | 0.38 ± 0.10     |
| $\Xi_c^0 \rightarrow \Sigma^0 \bar{K}^0$ | 0.07 ± 0.67                 | 0.11 ± 0.07     |
| $\Xi_c^0 \rightarrow \Lambda \bar{K}^0$ | $-0.85 \pm 0.36$           | 0.68 ± 0.49     |

*Input, $^1$For $\phi_{phy} = -10^0$, $^2$For $\phi_{phy} = -19^0$
Table II(a) Branching ratios and asymmetries of CS \((B_c \rightarrow BP)\) decays for 
\(B(\Lambda_c^+ \rightarrow \Xi^0 K^+) = -16.52 \pm 2.19\).

| Decay         | Asymmetry | \(Br\%\)  |
|---------------|-----------|-----------|
| \(\Lambda_c^+ \rightarrow p\pi^0\) | 0.05      | 0.02      |
| \(\Lambda_c^+ \rightarrow n\pi^+\) | 0.05      | 0.04      |
| \(\Lambda_c^+ \rightarrow \Lambda K^+\) | -0.54     | 0.14      |
| \(\Lambda_c^+ \rightarrow \Sigma^+ K^0\) | 0.68      | 0.09      |
| \(\Lambda_c^+ \rightarrow \Sigma^0 K^+\) | 0.68      | 0.04      |
| \(\Lambda_c^+ \rightarrow p\eta\) | \(-0.74^{+1}_{-0.69^{2}}\) | 0.21^{1} (0.17^{2}) |
| \(\Lambda_c^+ \rightarrow p\eta'\) | \(-0.97^{1}_{-0.99^{2}}\) | 0.04^{1} (0.06^{2}) |
| \(\Xi_c^+ \rightarrow pK^0\) | 0.87      | 0.19      |
| \(\Xi_c^+ \rightarrow \Lambda\pi^+\) | 0.65      | 0.23      |
| \(\Xi_c^+ \rightarrow \Xi^0 K^+\) | 0.08      | 0.03      |
| \(\Xi_c^+ \rightarrow \Sigma^+\pi^0\) | -0.89     | 0.28      |
| \(\Xi_c^+ \rightarrow \Sigma^0\pi^+\) | -0.90     | 0.28      |
| \(\Xi_c^+ \rightarrow \Sigma^+\eta\) | \(-0.75^{1}_{-0.81^{2}}\) | 0.19^{1} (0.21^{2}) |
| \(\Xi_c^+ \rightarrow \Sigma^+\eta'\) | \(-0.56^{1}_{-0.14^{2}}\) | 0.02^{1} (0.02^{2}) |
| \(\Xi_c^0 \rightarrow pK^-\) | -0.00     | 0.03      |
| \(\Xi_c^0 \rightarrow nK^0\) | -0.58     | 0.04      |
| \(\Xi_c^0 \rightarrow \Lambda\pi^0\) | 0.65      | 0.03      |
| \(\Xi_c^0 \rightarrow \Sigma^+\pi^-\) | -0.00     | 0.03      |
| \(\Xi_c^0 \rightarrow \Sigma^0\pi^0\) | -0.18     | 0.01      |
| \(\Xi_c^0 \rightarrow \Sigma^-\pi^+\) | -0.99     | 0.08      |
| \(\Xi_c^0 \rightarrow \Xi^- K^+\) | -0.92     | 0.06      |
| \(\Xi_c^0 \rightarrow \Xi^0 K^0\) | -0.40     | 0.04      |
| \(\Xi_c^0 \rightarrow \Lambda\eta\) | 0.26^{1} (0.83^{2}) | 0.005^{1} (0.003^{2}) |
| \(\Xi_c^0 \rightarrow \Lambda\eta'\) | \(-0.82^{1}_{-0.77^{2}}\) | 0.02^{1} (0.02^{2}) |
| \(\Xi_c^0 \rightarrow \Sigma^0\eta\) | \(-0.75^{1}_{-0.81^{2}}\) | 0.03^{1} (0.03^{2}) |
| \(\Xi_c^0 \rightarrow \Sigma^0\eta'\) | \(-0.56^{1}_{-0.14^{2}}\) | 0.003^{1} (0.002^{2}) |

\(^1\text{For } \phi_{phy} = -10^0, \text{ }^2\text{For } \phi_{phy} = -19^0\)
Table II(b) Branching ratios and asymmetries of CS ($B_c \rightarrow BP$) decays for $B(\Lambda_c^+ \rightarrow \Xi^0 K^+) = +16.52 \pm 2.19$

| Decay                  | Asymmetry            | $Br\%$         |
|------------------------|-----------------------|----------------|
| $\Lambda_c^+ \rightarrow p\pi^0$ | 0.05                  | 0.02           |
| $\Lambda_c^+ \rightarrow n\pi^+$ | 0.05                  | 0.04           |
| $\Lambda_c^+ \rightarrow \Lambda K^+$ | 0.97                  | 0.02           |
| $\Lambda_c^+ \rightarrow \Sigma^+ K^0$ | -0.98                | 0.12           |
| $\Lambda_c^+ \rightarrow \Sigma^0 K^+$ | -0.98                | 0.06           |
| $\Lambda_c^+ \rightarrow p\eta$ | -0.45$^1$ (-0.03$^2$) | 0.04$^1$ (0.02$^2$) |
| $\Lambda_c^+ \rightarrow p\eta'$ | -0.99$^1$ (-0.99$^2$) | 0.05$^1$ (0.06$^2$) |
| $\Xi_c^+ \rightarrow pK^0$ | -0.98                | 0.36           |
| $\Xi_c^+ \rightarrow \Lambda\pi^+$ | -0.79                | 0.14           |
| $\Xi_c^+ \rightarrow \Xi^0 K^+$ | 0.08                 | 0.03           |
| $\Xi_c^+ \rightarrow \Sigma^+ \pi^0$ | -0.18               | 0.08           |
| $\Xi_c^+ \rightarrow \Sigma^0 \pi^+$ | -0.18               | 0.08           |
| $\Xi_c^+ \rightarrow \Sigma^+ \eta$ | -0.98$^1$ (-0.98$^2$) | 0.08$^1$ (0.11$^2$) |
| $\Xi_c^+ \rightarrow \Sigma^+ \eta'$ | -0.99$^1$ (-0.99$^2$) | 0.05$^1$ (0.03$^2$) |
| $\bar{\Xi}_c^0 \rightarrow pK^-$ | 0.00                 | 0.03           |
| $\bar{\Xi}_c^0 \rightarrow nK^0$ | -0.58                | 0.04           |
| $\bar{\Xi}_c^0 \rightarrow \Lambda\pi^0$ | -0.79               | 0.02           |
| $\bar{\Xi}_c^0 \rightarrow \Sigma^+ \pi^-$ | 0.00               | 0.03           |
| $\bar{\Xi}_c^0 \rightarrow \Sigma^0 \pi^0$ | -0.89              | 0.04           |
| $\bar{\Xi}_c^0 \rightarrow \Sigma^- \pi^+$ | -0.99              | 0.08           |
| $\bar{\Xi}_c^0 \rightarrow \Xi^- K^+$ | -0.92               | 0.06           |
| $\bar{\Xi}_c^0 \rightarrow \Xi^0 K^0$ | -0.40               | 0.04           |
| $\bar{\Xi}_c^0 \rightarrow \Lambda\eta$ | -0.89$^1$ (-0.88$^2$) | 0.02$^1$ (0.009$^2$) |
| $\bar{\Xi}_c^0 \rightarrow \Lambda\eta'$ | -0.99$^1$ (-0.99$^2$) | 0.04$^1$ (0.04$^2$) |
| $\bar{\Xi}_c^0 \rightarrow \Sigma^0 \eta$ | -0.98$^1$ (-0.98$^2$) | 0.01$^1$ (0.02$^2$) |
| $\bar{\Xi}_c^0 \rightarrow \Sigma^0 \eta'$ | -0.99$^1$ (-0.99$^2$) | 0.006$^1$ (0.005$^2$) |

$^1$For $\phi_{phy} = -10^0$, $^2$For $\phi_{phy} = -19^0$
Table III(a) Branching ratios and asymmetries of CDS ($B_c \to BP$) decays for $B(\Lambda_c^+ \to \Xi^0K^+) = -16.52 \pm 2.19$

| Decay                  | Asymmetry | $Br\% \times (\tan^2\theta_{bc})$ |
|------------------------|-----------|-----------------------------------|
| $\Lambda_c^+ \to pK^0$| 0.03      | 3.15                              |
| $\Lambda_c^+ \to nK^+$ | 0.03      | 3.16                              |
| $\Xi_c^+ \to p\pi^0$  | -0.00     | 1.41                              |
| $\Xi_c^+ \to n\pi^+$  | -0.00     | 2.82                              |
| $\Xi_c^+ \to \Lambda K^+$ | 0.56     | 0.54                              |
| $\Xi_c^+ \to \Sigma^+ K^0$ | -0.97 | 4.39                              |
| $\Xi_c^+ \to \Sigma^0 K^+$ | -0.97 | 2.19                              |
| $\Xi_c^+ \to p\eta$   | 0.52 (0.76) | 1.47 (1.15)                     |
| $\Xi_c^+ \to p\eta'$  | -0.89 (−0.80) | 1.41 (1.68)                 |
| $\Xi_c^0 \to p\pi^-$  | -0.00     | 0.79                              |
| $\Xi_c^0 \to n\pi^0$  | -0.00     | 0.40                              |
| $\Xi_c^0 \to \Lambda K^0$ | 0.56     | 0.15                              |
| $\Xi_c^0 \to \Sigma^0 K^0$ | -0.97 | 0.62                              |
| $\Xi_c^0 \to \Sigma^- K^+$ | -0.97 | 1.24                              |
| $\Xi_c^0 \to n\eta$   | 0.52 (0.76) | 0.41 (0.32)                     |
| $\Xi_c^0 \to n\eta'$  | -0.89 (−0.80) | 0.39 (0.47)                 |

$^1$For $\phi_{phy} = -10^0$, $^2$For $\phi_{phy} = -19^0$
Table III(b) Branching ratios and asymmetries of CDS ($B_c \to BP$) decays for $B(\Lambda_c^+ \to \Xi^0 K^+) = +16.52 \pm 2.19$

| Decay      | Asymmetry | $Br\%$ ($\times tan^2 \phi_{phy}$) |
|------------|-----------|-----------------------------------|
| $\Lambda_c^+ \to pK^0$ | -0.19     | 0.06                              |
| $\Lambda_c^+ \to nK^+$  | -0.19     | 0.06                              |
| $\Xi_c^+ \to p\pi^0$   | 0.00      | 1.41                              |
| $\Xi_c^+ \to n\pi^+$   | 0.00      | 2.82                              |
| $\Xi_c^+ \to \Lambda K^+$ | 0.56   | 0.54                              |
| $\Xi_c^+ \to \Sigma^+ K^0$ | -0.97 | 4.39                              |
| $\Xi_c^+ \to \Xi^0 K^+$ | -0.97     | 2.19                              |
| $\Xi_c^+ \to p\eta$    | -0.89\(^1\) (-0.72\(^2\)) | 1.88\(^1\) (1.12\(^2\))         |
| $\Xi_c^+ \to p\eta'$   | -0.94\(^1\) (-0.96\(^2\)) | 3.05\(^1\) (3.56\(^2\))         |
| $\Xi_c^0 \to p\pi^-$   | 0.00      | 0.79                              |
| $\Xi_c^0 \to n\pi^0$   | 0.00      | 0.40                              |
| $\Xi_c^0 \to \Lambda K^0$ | 0.56  | 0.15                              |
| $\Xi_c^0 \to \Sigma^0 K^0$ | -0.97 | 0.62                              |
| $\Xi_c^0 \to \Sigma^- K^+$ | -0.97 | 1.24                              |
| $\Xi_c^0 \to n\eta$    | -0.89\(^1\) (-0.72\(^2\)) | 0.53\(^1\) (0.32\(^2\))         |
| $\Xi_c^0 \to n\eta'$   | -0.94\(^1\) (-0.96\(^2\)) | 0.86\(^1\) (0.99\(^2\))         |

\(^1\)For $\phi_{phy} = -10^0$, \(^2\)For $\phi_{phy} = -19^0$
Table IV Branching ratios of CF ($B_c \rightarrow DP$) decays.

| Decay                      | $Br\%$          |
|----------------------------|-----------------|
| $\Lambda_c^+ \rightarrow \Delta^{++} K^-$ | $0.70 \pm 0.40^*$ |
| $\Lambda_c^+ \rightarrow \Delta^+ K^0$     | $0.23 \pm 0.13$  |
| $\Lambda_c^+ \rightarrow \Sigma^{++} \pi^0$ | $0.46 \pm 0.18$  |
| $\Lambda_c^+ \rightarrow \Sigma^{*+} \eta$   | $0.21 \pm 0.11^1 (0.14 \pm 0.10^2)$ |
| $\Lambda_c^+ \rightarrow \Sigma^0 \pi^+$     | $0.46 \pm 0.18$  |
| $\Lambda_c^+ \rightarrow \Xi^0 K^+$          | $0.23 \pm 0.09^*$ |
| $\Xi_c^+ \rightarrow \Sigma^{*+} \bar{K}^0$  | $0.00$           |
| $\Xi_c^+ \rightarrow \Xi^* \pi^+$            | $0.00$           |
| $\Xi_c^0 \rightarrow \Sigma^{*+} K^-$        | $0.13 \pm 0.07$  |
| $\Xi_c^0 \rightarrow \Sigma^0 K^0$           | $0.06 \pm 0.04$  |
| $\Xi_c^0 \rightarrow \Xi^0 \pi^0$           | $0.26 \pm 0.10$  |
| $\Xi_c^0 \rightarrow \Xi^0 \eta$            | $0.13 \pm 0.06^1 (0.08 \pm 0.06^2)$ |
| $\Xi_c^0 \rightarrow \Xi^{-} \pi^+$          | $0.50 \pm 0.20$  |
| $\Xi_c^0 \rightarrow \Omega^- K^+$           | $0.45 \pm 0.18$  |

*Input, $^1$For $\phi_{phy} = -10^0$, $^2$For $\phi_{phy} = -19^0$
Table V Branching ratios of CS ($B_c \rightarrow DP$) decays.

| Decay                  | $Br\%$              |
|------------------------|---------------------|
| $\Lambda_c^+ \rightarrow \Delta^{++}\pi^-$ | 0.05                |
| $\Lambda_c^+ \rightarrow \Delta^{++}\pi^0$ | 0.08                |
| $\Lambda_c^+ \rightarrow \Delta^+\eta$  | $0.0005^1$ ($0.00001^2$) |
| $\Lambda_c^+ \rightarrow \Delta^+\eta'$ | $0.002^1$ ($0.002^2$) |
| $\Lambda_c^+ \rightarrow \Delta^0\pi^+$   | 0.08                |
| $\Lambda_c^+ \rightarrow \Sigma^{**}K^0$  | 0.006               |
| $\Lambda_c^+ \rightarrow \Sigma^{*0}K^+$  | 0.01                |
| $\Xi_c^+ \rightarrow \Delta^{++}K^-$       | 0.12                |
| $\Xi_c^+ \rightarrow \Delta^+\bar{K}^0$   | 0.04                |
| $\Xi_c^+ \rightarrow \Sigma^{**}\pi^0$    | 0.07                |
| $\Xi_c^+ \rightarrow \Sigma^{**}\eta$    | $0.04^1$ ($0.03^2$) |
| $\Xi_c^+ \rightarrow \Sigma^{**}\eta'$   | $0.007^1$ ($0.009^2$) |
| $\Xi_c^+ \rightarrow \Sigma^{*0}\pi^+$   | 0.07                |
| $\Xi_c^+ \rightarrow \Xi^{*0}K^+$         | 0.06                |
| $\Xi_c^0 \rightarrow \Delta^+\bar{K}^-$   | 0.01                |
| $\Xi_c^0 \rightarrow \Delta^0\bar{K}^0$   | 0.01                |
| $\Xi_c^0 \rightarrow \Sigma^+\pi^-$       | 0.009               |
| $\Xi_c^0 \rightarrow \Sigma^0\pi^0$       | 0.06                |
| $\Xi_c^0 \rightarrow \Sigma^0\eta$       | $0.008^1$ ($0.004^2$) |
| $\Xi_c^0 \rightarrow \Sigma^0\eta'$      | $0.004^1$ ($0.004^2$) |
| $\Xi_c^0 \rightarrow \Sigma^{*-}\pi^+$    | 0.16                |
| $\Xi_c^0 \rightarrow \Xi^{*0}K^0$         | 0.004               |
| $\Xi_c^0 \rightarrow \Xi^{*-}K^+$          | 0.06                |

$^1$For $\phi_{phy} = -10^0$, $^2$For $\phi_{phy} = -19^0$
Table VI Branching ratios of CDS ($B_c \rightarrow DP$) decays.

| Decay                        | $Br\% \,(×\tan^4_θ)$ |
|------------------------------|------------------------|
| $\Lambda_c^+ \rightarrow \Delta^+ K^0$ | 0                      |
| $\Lambda_c^0 \rightarrow \Delta^0 K^+$ | 0                      |
| $\Xi_c^+ \rightarrow \Delta^{++} \pi^-$ | 3.00                   |
| $\Xi_c^+ \rightarrow \Delta^{+} \pi^0$ | 4.79                   |
| $\Xi_c^+ \rightarrow \Delta^0 \pi^+$ | 4.39                   |
| $\Xi_c^+ \rightarrow \Sigma^{*0} K^+$ | 0.99                   |
| $\Xi_c^+ \rightarrow \Sigma^{*+} K^0$ | 0.45                   |
| $\Xi_c^+ \rightarrow \Delta^+ \eta$  | $0.03^1 \,(0.0001^2)$  |
| $\Xi_c^+ \rightarrow \Delta^+ \eta'$ | $0.38^1 \,(0.39^2)$    |
| $\Xi_c^0 \rightarrow \Delta^+ \pi^-$ | 0.28                   |
| $\Xi_c^0 \rightarrow \Delta^- \pi^+$ | 3.73                   |
| $\Xi_c^0 \rightarrow \Delta^0 \pi^0$ | 1.36                   |
| $\Xi_c^0 \rightarrow \Sigma^{*-} K^+$ | 0.56                   |
| $\Xi_c^0 \rightarrow \Sigma^{*0} K^0$ | 0.06                   |
| $\Xi_c^0 \rightarrow \Delta^0 \eta$  | $0.01^1 \,(0.00002^2)$ |
| $\Xi_c^0 \rightarrow \Delta^0 \eta'$ | $0.11^1 \,(0.11^2)$   |

$^1$For $\phi_{phy} = -10^0$, $^2$For $\phi_{phy} = -19^0$
References

[1] Particle Data Group, L. Montanet et al., Phys. Rev. D 50, 1225 (1994).

[2] CLEO collaboration, R. Ammar et. al., Phys. Rev. Lett. 74, 3534 (1995).

[3] CLEO Collaboration, M. Bishai et. al., Phys. Lett. B 350, 256 (1995).

[4] CLEO Collaboration, K. W. Edwards et. al. Phys. Lett. B 373, 261 (1996).

[5] R. E. Marshak, Riazzuddin, and C. P. Ryan, Theory of Weak Interactions in Particle Physics (Wiley, New York, 1969).

[6] S. Pakvasa, S. F. Tuan, and S. P. Rosen, Phys. Rev. D 42, 3746 (1990); G. Turan and J. O. Eeg, Z. Phys. C 51, 599 (1991); R. E. Karlsen and M. D. Scadron, Europhys. Lett. 14, 319 (1991); G. Kaur and M. P. Khanna, Phys. Rev. D 44, 182 (1991); J. G. Körner and H. W. Siebert, Annu. Rev. Nucl. Part. Sci. 41, 511 (1991); Q. P. Xu and A. N. Kamal, Phys. Rev. D 46, 270 (1992); G. Kaur and M. P. Khanna, Phys. Rev. D 45, 3024 (1992); H. Y. Cheng et al., Phys. Rev. D 46, 5060 (1992); P. Zenczykowski, Phys. Rev. D 50, 402 (1994), 5787 (1994); T. Uppal, R. C. Verma, and M. P. Khanna, Phys. Rev. D 49, 3417 (1994).

[7] G. Altarelli, N. Cabibbo and L. Maiani, Phys. Lett. B 57, 277 (1978).

[8] M. J. Savage and R. P. Springer, Phys. Rev. D 42, 1527 (1990).

[9] J. G. Körner, G. Kramer, and J. Willrodt, Z. Phys. C 1, 269 (1979); S. M. Sheikholeslami, M. P. Khanna, and R. C. Verma, Phys. Rev. D 43, 170 (1990); J. G. Körner and M. Krämer, Z. Phys. C 55, 659 (1992); M. P. Khanna, Phys. Rev. D 49, 5921 (1994).

[10] R. C. Verma and M. P. Khanna, Phys. Rev. D 53, 3723 (1996).

[11] H. Y. Cheng and B. Tseng, Phys. Rev. D 46, 1042 (1992); 48, 4188 (1993).

[12] J. G. Körner, G. Kramer and J. Willrodt, Z. Phys. C 2, 117 (1979); Q. P. Xu and A. N. Kamal, Phys. Rev. D 46, 3836 (1992).
[13] Y. Kohara, Phys. Rev. D 44, 2799 (1991).

[14] T. A. Kaeding and I. Hinchliffe, “Broken SU(3) symmetry in charm meson decays,” Berkeley report (unpublished); L. L. Chau and H. Y. Cheng, Phys. Lett. B 333, 515 (1994); F. Buccella et. al., Phys. Rev. D 51, 3478 (1995).