Nonleptonic Charmed-Baryon Decays: Symmetry Properties of Parity Violating Amplitudes

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December 13, 1993

Abstract

We study effects of pole-model-induced $SU(4)$ -symmetry breaking in parity violating amplitudes of Cabibbo-favoured nonleptonic decays of charmed baryons. A simple technique generalizing the expressions of current algebra to the case of flavour symmetry breaking in the intermediate state is applied to sum the contributions from all intermediate excited $1/2^-$ baryons of given charm. The technique permits easy discussion of departures from current algebra for any values of $\Delta c/\Delta\omega$ (Δc - charm-noncharm mass difference, $\Delta\omega$ - $1/2^- - 1/2^+$ mass difference). We find that in the pole model the symmetry structure of parity violating amplitudes of charmed baryon decays into an octet baryon and an octet pseudoscalar meson consists of two pieces: (i) a term proportional to the standard current algebra expression but much smaller and of *opposite* sign and (ii) a term proportional to the factorization contribution, interfering with it destructively. Symmetry structure of parity violating amplitudes for decays with vector meson production is also given. We apply the full pole model to the description of available data, compare it with the results of current algebra and indicate places where good discrimination between the pole model and current algebra should be possible.

PACS numbers: 13.30.Eg, 14.20.Kp

1 Introduction

As more and more data on nonleptonic decays of charmed baryons is accumulated, we are slowly approaching the moment when phenomenological discrimination between competing theoretical descriptions of these processes will become possible. Two main theoretical approaches are being studied. The first, based on quark diagrams and symmetry principles, was originally attempted by Körner and collaborators [1]. The second, followed by Cheng and Tseng [2] and Xu and Kamal [3] consists in carrying out explicit calculations in the framework of the pole model.

In a recent paper [4] a new analysis formulated in the language of quark diagrams has been presented. An essential part of that paper was devoted to the elucidation of how the symmetry structure of parity conserving amplitudes of the standard pole model is to be generated in a genuine quark-diagram scheme. It was shown that the presence of energy denominators corresponding to the propagation of ground-state baryons in the intermediate state affects the relative sign with which the spin-flavour factors corresponding to two types of quark diagrams are to be added: the sign resulting from the pole model prescription is *opposite* to the one inherent in the approach of ref.[1]. This constituted the main difference of the quark diagram approach of ref.[4] with respect to the scheme of ref.[1].

Contrary to the case of parity conserving amplitudes, the parity violating amplitudes were treated in both references [1] and [4] in similar ways. That is, the intermediate excited $1/2^-$ baryons were implicitly assumed much heavier than the ground-state charmed baryons under consideration. In other words,

in refs.[1, 4] quark mass differences $m_c - m_{u,d,s}$ were treated as negligible when compared to the splitting $\Delta\omega$ between the $1/2^+$ ground-state and the $1/2^-$ excited-state baryons. Such an assumption constitutes one of the conditions necessary to reduce pole model to current algebra (CA). Another ingredient of the PCAC/CA approach is that the emitted pseudoscalar meson is soft.

For hyperon decays, where $(m_s - m_{u,d})/\Delta\omega \approx 1/3$ and $m_s - m_{u,d} \approx m_\pi$, the CA prescription for parity violating amplitudes may constitute a fair approximation to that of the pole model, although even there significant differences between CA and pole model predictions may be observed [7, 5]. For charmed baryon decays $(m_c - m_{u,d,s})/\Delta\omega \approx 2.5 \pm 0.5$ (see Section 2). Consequently, one expects the pole model predictions to be totally different from that of current algebra.

It is the purpose of this paper to discuss the modifications of the quark-diagram approach of ref.[4] to the case when the parity violating amplitudes are evaluated by the ($SU(4)$ -breaking) $1/2^-$ pole model prescription. We will be interested in the $SU(4)$ breaking effects arising from energy denominators of the pole model only. We will not consider the dependence on meson momenta whose nonzero values also question the applicability of current algebra. Study of the momentum dependence needs the introduction of more specific models, like the bag model considered in ref.[2, 6]. However, we do not think that consideration of momentum dependence could qualitatively change the results of this paper which are of a group-theoretical nature.

In Section 2 using a recently developed simple technique [5] we reproduce results obtained previously in conventional $SU(4)$ -breaking pole models [2, 6]. The main advantage of our approach is that we gain a much better insight

into the symmetry structure of the pole model and the general tendency of its deviations from the predictions of current algebra. It appears that for the $B_c \rightarrow BP$ decays (B_c - charmed baryon from the antitriplet, B - octet baryon, P - octet pseudoscalar meson) the baryon-pole contribution to the parity violating amplitudes consists of two pieces of familiar symmetry structure: the first is proportional to the current algebra prescription (though much smaller and of *opposite* sign), the other is proportional to the factorisation contribution with which it interferes *destructively*. Similarly, for the $B_c \rightarrow BV$ decays (V - vector meson) the baryon-pole contribution to the parity violating amplitudes consists of two pieces (separately for transverse and longitudinal vector mesons) but in this case no term proportional to the factorization contribution is present. By casting the structure of pole model into the language of quark diagrams a comparison with the approach of Körner [1] as regards the dependence of the amplitudes on charmed quark mass can also easily be made.

In Section 3 predictions of our scheme are compared with the most recent data. With the possible exception of the $\Lambda_c^+ \rightarrow \Sigma^+ \pi^0$ asymmetry (for which the pole model predicts a small positive value, while experiment and CA yield negative numbers) the agreement with the data is good. We discuss briefly how one can alleviate the problem of the $\Lambda_c^+ \rightarrow \Sigma^+ \pi^0$ asymmetry and indicate other decay channels where a cleaner discrimination between current algebra and pole model should be possible.

2 Symmetry structure of parity violating amplitudes

Description of parity violating amplitudes in the framework of the pole model is usually regarded as less reliable than that of parity conserving amplitudes since the former involves weak transition matrix elements and strong coupling constants of $1/2^-$ excited baryons of which we know much less than of ground-state baryons relevant for the latter. One of the reasons of the attractiveness of current algebra is that it bypasses the need to know anything about the troublesome $1/2^-$ poles - their summed-over contribution is hidden in the final CA formulas. It turns out, however, that one can easily maintain this virtue of current algebra and yet discuss flavour symmetry breaking characteristic of the pole model. Such an approach phrased in terms of quark diagrams has recently been developed in ref.[5] for the specific case of weak hyperon decays. In ref.[5] it was shown how the relative weights of the two terms of the CA commutator $A^0 H^{p.v.} - H^{p.v.} A^0$ (which correspond to appropriate two terms in the pole model) are to be modified when $SU(3)$ symmetry breaking in energy denominators of the pole model is to be considered. In the present paper we apply the basic idea of ref.[5] to the case of nonleptonic decays of charmed baryons.

The quark diagrams relevant for the nonleptonic charmed baryon decays are shown in Fig.1. Diagrams (a) and (a') correspond to the factorization amplitudes. For the parity violating amplitudes the contribution from diagrams (d) vanishes. The pole model contribution from the intermediate $1/2^-$ baryons is contained in the W -exchange diagrams (b1) and (b2). In ref.[4] the

quark-model technique of refs. [8, 9] was used to determine sums of spin-flavour factors corresponding to these diagrams. Consideration of $SU(4)$ symmetry breaking requires knowledge of spin-flavour factors of the individual diagrams (b1) and (b2). For the sake of the ensuing discussion it is more appropriate to present their sums and differences rather than the individual factors. Since the sums have already been tabulated in ref.[4] it would suffice here to give the differences only. We have gathered all of them (appropriate for transitions $B_c \rightarrow BP$, $B_c \rightarrow BV_\perp$ and $B_c \rightarrow BV_\parallel$) in Table 1 (in columns denoted b1 – b2). For better clarity of the exposition two additional columns have been taken from ref.[4] and added to Table 1: (1) the sums of the spin-flavour factors for the $B_c \rightarrow BP$ decays (b1 + b2, P) and (2) the contributions from the factorization diagrams.

Denoting by $b_1(i)$ and $b_2(i)$ the spin-flavour weights corresponding to a given decay i , the pole model expression for the parity violating amplitude is proportional to

$$\frac{b_1(i)}{-B_c + B_s^*} + \frac{b_2(i)}{-B_s + B_c^*} \quad (1)$$

In Eq.1 baryon masses have been denoted in a self-explanatory way: B_c , B_c^* denote the masses of the decaying charmed baryon and the intermediate $1/2^-$ excited charmed baryons, respectively. Similarly, B_s and B_s^* denote the masses of corresponding hyperons connected through the $c \, d \rightarrow s \, u$ weak parity violating transition with B_c^* and B_c . Please note that in Eq.1 contributions from intermediate $1/2^-$ baryons of given charm are already summed over. Thus, the relative signs of various individual contributions are taken care of

automatically. We estimate

$$\begin{aligned} B_c^* - B_s &\approx 2750 - 1150 = 1600 \text{ MeV} \\ B_s^* - B_c &\approx 1700 - 2350 = -650 \text{ MeV} \end{aligned} \quad (2)$$

Since

$$\begin{aligned} B_c^* - B_s &\approx m_c + \Delta\omega - m_s \\ B_s^* - B_c &\approx m_s + \Delta\omega - m_c \end{aligned} \quad (3)$$

we obtain (effective) values

$$\begin{aligned} \Delta\omega &\approx 475 \text{ MeV} \\ m_c - m_s &\approx 1125 \text{ MeV} \end{aligned} \quad (4)$$

and

$$\Delta c / \Delta\omega = (m_c - m_s) / \Delta\omega \approx 2.4 \quad (5)$$

Other estimates of the ratio $\Delta c / \Delta\omega$ give values in the range 2 to 3 or even more.

Eq.1 may be rewritten (*without making any approximation*) as

$$\frac{1}{\Delta\omega} \left\{ [b_1(i) + b_2(i)] + [b_1(i) - b_2(i)] \frac{\Delta c}{\Delta\omega} \right\} \frac{1}{1 - (\frac{\Delta c}{\Delta\omega})^2} \quad (6)$$

The full parity violating amplitude of the pole model is obtained from Eq.6 by its multiplication by appropriate coupling constants what amounts to replacing the overall factor of $1/\Delta\omega$ by $\tilde{b} = b \cot \theta_c = -22.2$ (in units of 10^{-7}) where b is the reduced matrix element extracted from hyperon decays (see ref.[4]).

From Eq.6 we see that in the pole model there are two contributions to the parity violating amplitudes. The first is proportional to $b_1(i) + b_2(i)$ i.e. it has the symmetry structure of the original current algebra term (obtainable from Eq.6 in the limit $\Delta c \rightarrow 0$). Its size and sign are, however, different: $1/[1 - (\Delta c/\Delta\omega)^2]$ changes from 1 at $\Delta c = 0$ to around -0.2 for realistic values of $\Delta c/\Delta\omega$. We might call this term an anti-CA piece. The second contribution has symmetry structure determined by the difference of spin-flavour factors $b_1(i) - b_2(i)$. One can see from Table 1 that for flavour octet pseudoscalar meson production this term is proportional to the sextet part of the factorization contribution (sextet-dominance requires $g = -g'$). The size of this pole-model induced contribution relative to the factorization term is (we assume $g \approx -g'$)

$$\zeta = -\frac{1}{6} \frac{\Delta c}{\Delta\omega} \frac{1}{1 - (\Delta c/\Delta\omega)^2} \frac{\bar{b}}{g}. \quad (7)$$

If one uses $g \approx 4.5$ from ref.[4] one gets $\zeta = -0.39 \pm_{0.16}^{0.08}$ for $\Delta c/\Delta\omega = 2.5 \pm 0.5$ i.e. a substantial *destructive* contribution. The above number is best compared with the pole model correction to the factorization contribution in the $\Lambda_c^+ \rightarrow \Lambda\pi^+$ parity violating amplitude of ref.[2], where $A^{pole}/A^{fac} = 1.95/(-5.40) = -0.36$. Similar agreement is found in other cases of interest. For example for $\Lambda_c^+ \rightarrow \Sigma^0\pi^+$ there is no factorization contribution and hence the whole difference between the pole model and current algebra prediction is given by the *multiplicative* factor of $1/(1 - (\Delta c/\Delta\omega)^2) \approx -0.19 \pm_{0.14}^{0.06}$ for $\Delta c/\Delta\omega = 2.5 \pm 0.5$. The corresponding number in ref.[2] is -0.32. Fits to experimental data performed in the current algebra + factorization framework will extract therefore an incorrect (i.e. reduced) value for the factorization

contribution in the parity violating sector if the $SU(4)$ -breaking pole model is correct. Because in such fits the "true" factorization contribution is bigger in pole model than in current algebra, the CA fits would suggest a stronger (than actual) breaking of sextet dominance in the factorization contribution (recall that the destructive baryon pole terms do satisfy sextet-dominance). In principle there is a simple way to distinguish between the predictions of simple current algebra and those of the $SU(4)$ -breaking pole model. Namely, one has to look at those processes where factorization cannot contribute, e.g. $\Lambda_c^+ \rightarrow \Sigma^+ \pi^0$. If one accepts that the structure of parity conserving amplitudes is in both cases described by the ground-state baryon pole terms (whose contribution is estimated similar by different authors - see e.g. refs.[3, 2, 6]) the change from CA to pole model for parity violating amplitudes will change the sign and the size (in some cases significantly) of the asymmetries of such processes. For the $\Lambda_c^+ \rightarrow \Sigma^+ \pi^0$ decay this explains the difference of asymmetry between ref.[2] and ref.[4]. We shall come back to the question of the $\Lambda_c^+ \rightarrow \Sigma^+ \pi^0$ asymmetry in the next section. The fact that the pole-model amplitude can be well approximated by Eq.6 where dependence on charmed quark mass is very simple permits an easy comparison [10] of this dependence with that of ref.[1]. Up to an overall normalization factor the relative contributions from diagrams (b1) and (b2) to $B_c \rightarrow BP$ parity violating amplitudes of ref.[1] may be cast in a form easily comparable with Eq.6:

$$b_1 \left(\frac{m_P}{\Delta\omega} - \frac{\Delta c}{\Delta\omega} \right) + b_2 \frac{\frac{m_P}{\Delta\omega} + \frac{\Delta c}{\Delta\omega}}{1 + \frac{1}{2} \frac{\Delta c}{\Delta\omega}} \quad (8)$$

if one approximates the mass of the noncharmed final baryon by $2\Delta\omega$ (m_P - mass of the pseudoscalar meson).

From Eq.8 one can see that for the approach of ref.[1] the diagram (b1) dominates over (b2) in the limit $\Delta c \rightarrow \infty$. On the other hand in the pole model (Eq.6) it is the difference of the spin-flavour weights from both diagrams that survives. (Thus, in the limit of very heavy charmed quark mass the ground-state baryon pole contribution to $B_c \rightarrow BP$ processes looks exactly like the factorization contribution, though its sign is opposite.) Although the two models agree at $\Delta c \rightarrow 0$ their predictions at other values of Δc are in general significantly different. For the realistic case of $\Delta c/\Delta \omega \approx 2.5$ this is not the case, however: in both models the contribution from diagram (b1) is a factor of roughly 1.5 to 3 bigger than the contribution from diagram (b2), and the relative signs of the two contributions are identical.

From Table 1 we also see that for the vector meson production the $b_1(i) - b_2(i)$ -type terms are not proportional to the factorization contributions (which, apart from the size of the corresponding reduced matrix elements, are given by the same formulas as for the $B_c \rightarrow BP$ decays). No linear combination of $b_1(i) - b_2(i)$ and $b_1(i) + b_2(i)$ terms is proportional to the factorization contribution either. (The $b_1(i) + b_2(i)$ terms for vector mesons should perhaps be called CA-like terms since they are symmetry-related equivalents of current algebra terms for pseudoscalars.) A comparison with Table 2 of ref.[4] shows that the $b_1(i) - b_2(i)$ terms for $V_\perp(V_\parallel)$ mesons have the symmetry structure of $b_1(i) + b_2(i)$ terms for $V_\parallel(V_\perp)$ mesons. The relevant (spin-related) proportionality factors are $\sqrt{2}(1/\sqrt{2})$ respectively (as indicated in Table 1). The appearance of nonzero $b_1(i) - b_2(i)$ terms for processes where there is no factorization contribution is important as it provides us with a possibility to discern more cleanly between current algebra and pole model (see next Section).

3 Description of Data and Discussion

In ref.[4] we have presented a CA fit to the experimental data. Significant differences existing between current algebra and the pole model and concerning the symmetry structure of parity violating amplitudes would certainly change the fit of ref.[4] in an essential way. In this section we shall give an exemplary description of the experimental data in the pole model - including results of the most recent measurements that have not been used in the fit of ref.[4]. There are several new data points that restrict the freedom of our approach quite significantly. These are the recently measured [11, 12] branching ratios for the $\Lambda_c^+ \rightarrow \Xi^0 K^+$, $\Lambda_c^+ \rightarrow \Sigma^+ \phi$ decays as well as the asymmetry of the process $\Lambda_c^+ \rightarrow \Sigma^+ \pi^0$. The reason why they are important is that they depend solely on the W -exchange processes. Moreover, in the case of $\Lambda_c^+ \rightarrow \Xi^0 K^+$ decay only the parity conserving amplitude is different from zero (see Table 1 and refs.[1, 3, 6]). The measured value of the $\Lambda_c^+ \rightarrow \Xi^0 K^+$ branching ratio sets therefore the scale of the W -exchange contribution to all parity conserving amplitudes. For convenience in Table 2 we reproduce (from ref.[4]) the quark-diagram expressions for the parity conserving amplitudes of the Λ_c^+ decays. (In Table 2 we have adopted quark-model relationships between the reduced matrix elements of $V_\perp$ and $V_\parallel$ sectors, see also ref.[4].)

In ref.[6] Cheng and Tseng have stressed that their pole-model prediction of the parity conserving amplitude of the $\Lambda_c^+ \rightarrow \Xi^0 K^+$ decay (as well as that of $\Xi_c^0 \rightarrow \Sigma^+ K^-$) is quite uncertain because the final number is a result of strong cancellations among the contributions from individual baryon poles. On the other hand no such cancellations are seen in our pole-model expression for this amplitude (see Table 2). The underlying reason is that all such cancellations

between contributions from different intermediate baryons have already been carried out when obtaining entries of Table 2. This cancellation corresponds to the cancellation of contributions from (*d*)-type diagrams (Fig.1) as discussed also in ref.[4].

Having the effective size of *W*-exchange contribution to parity conserving amplitudes roughly fixed by the $\Lambda_c^+ \rightarrow \Xi^0 K^+$ branching ratio (as well as other branching ratios, most notably that of $\Lambda_c^+ \rightarrow \Sigma^+ \phi$) we might proceed as in ref.[4] and fit the factorization contribution in parity conserving amplitudes and the overlap factor *r* (see ref.[13]) to the available data (introduction of *r* amounts to the replacement of $\bar{b}$ by $r\bar{b}$). For reasons discussed below the fit performed in the pole model with respect to *r* is meaningless, however. Namely, as it has been mentioned in the previous section, current algebra and pole model yield different predictions for the sign of the asymmetry of the $\Lambda_c^+ \rightarrow \Sigma^+ \pi^0$ decay. The asymmetry predicted by the pole model is positive (but small), in disagreement with recent experimental number [12], $\alpha = -0.43 \pm 0.30$. Thus, a very small value of *r* would be chosen by the fit. Therefore, one has to keep the value of *r* fixed. To give the reader a feeling for both $r = 0.5$ and $r = 1$ we decided to present results obtained for $r = 0.7$. Description of the available data obtained in this way preserves all qualitative features of the model we are interested in. Reasonable description of the branching ratios of the $\Lambda_c^+ \rightarrow \Xi^0 K^+$ and $\Lambda_c^+ \rightarrow \Sigma^+ \phi$ decays is obtained then with

$$B \approx -140 \tag{9}$$

(in units of 10^{-7}), to be compared with $B \approx -100$ in ref.[4]. The fit with respect to the size of the parity conserving part *M* (assuming $M' = -M$) of the factorization contribution (and keeping $g = -g' = 4.5$ as in ref.[4]) finds then

$M \approx 65$ (in units of 10^{-7}) to be compared with 45 in ref.[4] and $M \approx 95 \pm 20$ in ref.[2]. Description of the data and predictions of the model are given in Table 3. It is seen that there is a good agreement with the data apart from the already mentioned problem of the asymmetry of the $\Lambda_c^+ \rightarrow \Sigma^+ \pi^0$ decay. This problem has recently been discussed by Cheng and Tseng [6] who argued that the pole model provides a better description of the data than current algebra, despite the disagreement in the sign of the asymmetry. Their pole model calculation gives a small parity violating amplitude and a fairly large parity conserving amplitude of same sign thus yielding a positive asymmetry. Cheng and Tseng argued then that small corrections in parity violating amplitudes may flip the sign of the asymmetry. It is therefore interesting that in our approach we obtain a similar description of that decay channel with parity violating amplitude around -0.85 (in units of 10^{-7}) and parity conserving amplitude around -13.5. The size of the latter is determined by the branching ratios of $\Lambda_c^+ \rightarrow \Xi^0 K^+$ and $\Lambda_c^+ \rightarrow \Sigma^+ \phi$ as well as other processes.

Our pole model description of parity violating amplitudes includes contributions from the lowest $1/2^-$ excited states only. Within the general framework of the pole model one might expect small contributions from heavier intermediate states. These terms (apart from their small overall size) would behave like standard current algebra contribution (obtained when $1/2^-$ excitation energy is larger than flavour symmetry breaking). Such terms might reduce the small anti-CA contributions from lowest $1/2^-$ excited states (maybe even change their sign?). Fortunately, there is a place where such a cancellation is not likely. Namely, one can pinpoint several decays with *vector* meson production where the anti-CA(-like) piece (i.e. the $b_1 + b_2$ term) is additionally *enhanced* by the $b_1 - b_2$ correction (recall that for pseudoscalar meson production this

correction is present only in amplitudes with nonzero factorization terms and interferes with them destructively). Upon examining Table 1 and Table 2 of ref.[4] one can see that the cleanest examples are provided by three decays:

$$\begin{aligned}
\Xi_c^0 &\rightarrow \Sigma \bar{K}^{*-} \\
\Lambda_c^+ &\rightarrow \Xi^0 K^{*+} \\
\Lambda_c^+ &\rightarrow \Sigma^+ \phi
\end{aligned} \tag{10}$$

For these decays there is no factorization contribution while the $b_1 + b_2$ and $b_1 - b_2$ factors are identical and add coherently [14] lifting most of the suppression resulting from the $1/(1 - (\Delta c/\Delta \omega)^2)$ factor (see Eq.6). For these processes, therefore, the pole-model predictions for the signs of the asymmetries should be reliable. The pole model predicts fairly large positive asymmetries (+0.5 to +0.8) for all three decays listed in Eq.10 while current algebra corresponds to large negative numbers (compare ref.[4]) of comparable size. Small CA-like contributions from heavier excited states should not be able to change the sign of asymmetries for these decays. The above argument assumes that the cancellation in parity conserving amplitudes discussed in ref.[6] (which will occur in the vector sector as well) is reasonably well described by total cancellation of contributions from diagrams (d).

Our description of those decays with vector meson production where factorization terms can contribute should be treated with caution as a different pair of reduced matrix elements (a and a' , see ref.[4]) enters into the description. These terms dominate numerically the relevant parity violating amplitudes. However, although the sizes of a and a' affect branching ratios considerably, our predictions for the approximate size of the asymmetries in question should be considered fairly reliable. An important case is the asym-

metry of the $\Lambda_c^+ \rightarrow p\bar{K}^{*0}$ decay which is of some interest in the analysis of Λ_b decays [15]. In our $SU(4)$ breaking pole model approach this asymmetry is predicted positive and large, i.e. similar to the prediction of CA approach of ref.[4].

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Table 1. Weights of quark diagrams for parity violating $B_c \rightarrow BM$ amplitudes.

process	$b1 + b2$ P	$b1 - b2$ P	factorization $P(V)$	$b1 - b2$ $V_\perp$ $\sqrt{2}(b1 + b2)v_\parallel$	$b1 - b2$ $V_\parallel$ $(b1 + b2)v_\perp/\sqrt{2}$
$\Xi_c^+ \rightarrow \Xi^0 \pi^+(\rho^+)$	$-\frac{1}{2\sqrt{6}}$	$\frac{1}{2\sqrt{6}}$	$\sqrt{\frac{3}{2}}g'$	$\frac{1}{2\sqrt{3}}$	$-\frac{1}{2\sqrt{6}}$
$\Xi_c^+ \rightarrow \Sigma^+ \bar{K}^0(\bar{K}^{*0})$	$-\frac{1}{2\sqrt{6}}$	$\frac{1}{2\sqrt{6}}$	$-\sqrt{\frac{3}{2}}g$	$\frac{1}{2\sqrt{3}}$	$-\frac{1}{2\sqrt{6}}$
$\Xi_c^0 \rightarrow \Xi^0 \pi^0(\rho^0)$	$-\frac{1}{2\sqrt{3}}$	0	0	$\frac{2}{3\sqrt{6}}$	$-\frac{1}{6\sqrt{3}}$
$\Xi_c^0 \rightarrow \Xi^0 \eta_8(\omega)$	$\frac{1}{6}$	0	0	$-\frac{1}{3\sqrt{6}}$	$\frac{1}{3\sqrt{3}}$
$\Xi_c^0 \rightarrow \Xi^0 \eta_1(\phi)$	$-\frac{1}{6\sqrt{2}}$	$-\frac{1}{2\sqrt{2}}$	0	$-\frac{1}{6\sqrt{3}}$	$-\frac{1}{6\sqrt{6}}$
$\Xi_c^0 \rightarrow \Xi^- \pi^+(\rho^+)$	$\frac{1}{2\sqrt{6}}$	$\frac{1}{2\sqrt{6}}$	$\sqrt{\frac{3}{2}}g'$	$-\frac{1}{6\sqrt{3}}$	$-\frac{1}{6\sqrt{6}}$
$\Xi_c^0 \rightarrow \Sigma^0 \bar{K}^0(\bar{K}^{*0})$	$-\frac{1}{4\sqrt{3}}$	$\frac{1}{4\sqrt{3}}$	$-\frac{\sqrt{3}}{2}g$	$\frac{1}{6\sqrt{6}}$	$-\frac{5}{12\sqrt{3}}$
$\Xi_c^0 \rightarrow \Lambda \bar{K}^0(\bar{K}^{*0})$	$-\frac{1}{4}$	$-\frac{1}{12}$	$\frac{1}{2}g$	$\frac{1}{6\sqrt{2}}$	$-\frac{1}{12}$
$\Xi_c^0 \rightarrow \Sigma^+ K^-(K^{*-})$	0	0	0	$\frac{1}{3\sqrt{3}}$	$\frac{1}{3\sqrt{6}}$
$\Lambda_c^+ \rightarrow \Sigma^+ \pi^0(\rho^0)$	$-\frac{1}{2\sqrt{3}}$	0	0	$\frac{1}{3\sqrt{6}}$	$-\frac{1}{3\sqrt{3}}$
$\Lambda_c^+ \rightarrow \Sigma^+ \eta_8(\omega)$	$\frac{1}{6}$	0	0	$-\frac{2}{3\sqrt{6}}$	$\frac{1}{6\sqrt{3}}$
$\Lambda_c^+ \rightarrow \Sigma^+ \eta_1(\phi)$	$-\frac{1}{6\sqrt{2}}$	$-\frac{1}{2\sqrt{2}}$	0	$\frac{1}{6\sqrt{3}}$	$\frac{1}{6\sqrt{6}}$
$\Lambda_c^+ \rightarrow \Sigma^0 \pi^+(\rho^+)$	$\frac{1}{2\sqrt{3}}$	0	0	$-\frac{1}{3\sqrt{6}}$	$\frac{1}{3\sqrt{3}}$
$\Lambda_c^+ \rightarrow \Lambda \pi^+(\rho^+)$	0	$-\frac{1}{6}$	$-g'$	0	$\frac{1}{6}$
$\Lambda_c^+ \rightarrow \Xi^0 K^+(K^{*+})$	0	0	0	$\frac{1}{3\sqrt{3}}$	$\frac{1}{3\sqrt{6}}$
$\Lambda_c^+ \rightarrow p \bar{K}^0(\bar{K}^{*0})$	$\frac{1}{2\sqrt{6}}$	$\frac{1}{2\sqrt{6}}$	$-\sqrt{\frac{3}{2}}g$	$-\frac{1}{6\sqrt{3}}$	$-\frac{1}{6\sqrt{6}}$

Table 2. Parity conserving weak amplitudes for $\Lambda_c^+ \rightarrow BM$ decays.

process	B_P	B_{V_1}	$B_{V_{ }}$
$\Lambda_c^+ \rightarrow \Sigma^+ \pi^0(\rho^0)$	$\frac{1}{6\sqrt{3}}B$	$-\frac{1}{3\sqrt{6}}B$	$-\frac{1}{2\sqrt{3}}B$
$\Lambda_c^+ \rightarrow \Sigma^+ \eta_8(\omega)$	$-\frac{1}{6}B$	$\frac{2}{3\sqrt{6}}B$	0
$\Lambda_c^+ \rightarrow \Sigma^+ \eta_1(\phi)$	$-\frac{1}{6\sqrt{2}}B$	$-\frac{1}{6\sqrt{3}}B$	$-\frac{1}{2\sqrt{6}}B$
$\Lambda_c^+ \rightarrow \Sigma^0 \pi^+(\rho^+)$	$-\frac{1}{6\sqrt{3}}B$	$\frac{1}{3\sqrt{6}}B$	$\frac{1}{2\sqrt{3}}B$
$\Lambda_c^+ \rightarrow \Lambda \pi^+(\rho^+)$	$\frac{1}{6}M'$	$-\frac{1}{3\sqrt{2}}M'$	$\frac{1}{6}M'$
$\Lambda_c^+ \rightarrow \Xi^0 K^+(K^{*+})$	$\frac{1}{3\sqrt{6}}B$	$-\frac{1}{3\sqrt{3}}B$	0
$\Lambda_c^+ \rightarrow p \bar{K}^0(\bar{K}^{*0})$	$-\frac{1}{6\sqrt{6}}B + \frac{1}{2\sqrt{6}}M$	$\frac{1}{6\sqrt{3}}B - \frac{1}{2\sqrt{3}}M$	$\frac{1}{2\sqrt{6}}B + \frac{1}{2\sqrt{6}}M$

Table 3. Description of branching ratios and asymmetries

$\Lambda_c^+ \rightarrow$	this work		experiment	
	BR(%)	asym	BR(%)	asym
$\Sigma^+ \pi^0$	0.41	+0.39	0.63 ± 0.21	-0.43 ± 0.30
$\Sigma^+ \eta$	0.94	0.00		
$\Sigma^+ \eta'$	0.12	-0.91		
$\Sigma^0 \pi^+$	0.41	+0.39	0.55 ± 0.26	
$\Lambda \pi^+$	0.54	-0.99	0.58 ± 0.16	-1.03 ± 0.29
$\Xi^0 K^+$	0.36	0.00	0.25 ± 0.08	
$p \bar{K}^0$	1.79	-0.66	1.60 ± 0.40	
$\Sigma^+ \rho^0$	1.56	-0.18		
$\Sigma^+ \omega$	1.10	+0.36		
$\Sigma^+ \phi$	0.11	+0.51	0.22 ± 0.09	
$\Sigma^0 \rho^+$	1.56	-0.18		
$\Lambda \rho^+$	1.80	+0.60		
$\Xi^0 \bar{K}^{*+}$	0.11	+0.81		
$p \bar{K}^{*0}$	5.03	+0.90		
$p \phi$	0.14	+0.64	0.13 ± 0.9	

$\Xi_c^0 \rightarrow$	this work	
	BR(%)	asym
$\Xi^0 \pi^0$	0.69	+0.21
$\Xi^0 \eta$	0.01	-0.04
$\Xi^0 \eta'$	0.09	-1.00
$\Xi^- \pi^+$	0.61	-0.79
$\Sigma^0 \bar{K}^0$	0.11	-0.50
$\Lambda \bar{K}^0$	0.35	-0.29
$\Sigma^+ K^-$	0.36	0.00
$\Xi^0 \rho^0$	1.22	+0.15
$\Xi^0 \omega$	0.15	+0.09
$\Xi^0 \phi$	0.10	-0.08
$\Xi^- \rho^+$	1.50	0.87
$\Sigma^0 \bar{K}^{*0}$	0.77	+0.25
$\Lambda \bar{K}^{*0}$	1.15	+0.49
$\Sigma^+ K^{*-}$	0.37	+0.51

$\Xi_c^+ \rightarrow$	this work	
	BR(%)	asym
$\Xi^0 \pi^+$	1.59	+1.00
$\Sigma^+ \bar{K}^0$	1.56	+1.00
$\Xi^0 \rho^+$	5.48	-0.54
$\Sigma^+ \bar{K}^{*0}$	7.38	-0.52

Fig.1. Quark diagrams for weak decays of charmed baryons.