Single Pion Transitions of Charmed Baryons

Salam Tawfiq, Patrick J. O’Donnell

Department of Physics, University of Toronto
60 St. George Street, Toronto Ontario, M5S 1A7, Canada

and

J.G. Körner

Institut für Physik, Johannes Gutenberg-Universität
Staudinger Weg 7, D-55099 Mainz, Germany

May 1998

Abstract

The $SU(2N_f) \otimes O(3)$ constituent quark model symmetry of the light diquark system are used to analyze single pion transitions of S-wave to S-wave and P-wave to S-wave heavy baryons. We show that the Heavy Quark Symmetry (HQS) coupling factors are given in terms of the three independent couplings $g_{\Sigma Q \Lambda Q \pi}$, $f_{\Lambda Q_1 \Sigma Q \pi}$ and $f_{\Lambda Q_1 \Sigma Q \pi}^\ast$. Light-Front quark model spin wave functions are, then, employed to calculate these couplings and to predict decay rates of single pion transitions between charm baryon states.

1 A talk given at the MRST ‘98 conference, “Toward the Theory of Everything”, May 13-15, 1998. Montréal, Canada. To appear in the proceedings.
Heavy Quark Symmetry (HQS) and $SU(2N_f) \times O(3)$ light diquark symmetry can be used to construct heavy baryon spin wave functions a la Bethe-Salpater [1, 2]. These covariant wave functions were employed [3] to analyze current-induced bottom baryon to charm baryon transitions. Similar procedure will be followed here to study heavy baryon S-wave to S-wave and P-wave to S-wave single pion transitions. In single–pion transitions between heavy baryons, the pion is emitted by each of the light quarks while the heavy quark is unaffected. In fact, the heavy baryon velocity will not be changed when emitting the pion since it is infinitely massive and will not recoil.

In a heavy baryon, a light diquark system with quantum numbers $jP$ couples with a heavy quark with $J^P_Q = 1/2^+$ to form a doublet with $J^P = (j \pm 1/2)$. Heavy quark symmetry allows us to write down a general form for the heavy baryon spin wave functions [4, 3]. Ignoring isospin indices, one has

$$\chi_{\alpha\beta\gamma} = (\phi_{\mu_1\cdots\mu_j})_{\alpha\beta}\psi^\mu_{\gamma_1\cdots\mu_j}(v).$$

(1)

Here, $v = \frac{P}{M}$ is the baryon four velocity, $\mu_1 \cdots \mu_j$ are Lorentz indices, the spinor indices $\alpha$ and $\beta$ refer to the light quark system and the index $\gamma$ refers to the heavy quark. In the heavy quark limit, the $\chi_{\alpha\beta\gamma}$ satisfy the Bargmann-Wigner equation on the heavy quark index

$$(\not{\gamma} + 1)\chi_{\alpha\beta\gamma} = \chi_{\alpha\beta\gamma}.$$  

(2)

In general the light degrees of freedom spin wave functions $(\phi_{\mu_1\cdots\mu_j})_{\alpha\beta}$ are written in terms of the two bispinors $[\chi^0]_{\alpha\beta}$ and $[\chi^1]_{\alpha\beta}$. The matrix $[\chi^0]_{\alpha\beta} = [(\not{\gamma} + 1)\gamma_5C]_{\alpha\beta}$, projects out a spin-0 object, is symmetric when interchanging $\alpha$ and $\beta$. However, $[\chi^1]_{\alpha\beta} = [((\not{\gamma} + 1)\gamma_5C)\gamma_5]_{\alpha\beta}$ which projects out a spin-1 object is antisymmetric. Here, $C$ is the charge conjugation operator and $\gamma_5 = \gamma_\mu - \not{\gamma}\not{v}\gamma_\mu$. On the other hand the “superfield” $\psi_{\gamma_1\cdots\gamma_j}(v)$ stands for the two spin wave functions corresponding to the two heavy quark symmetry degenerate states with spins $(j \pm 1/2)$. They are generally written in terms of the Dirac spinor $u$ and the Rarita-Schwinger spinor $u_\mu$.

The S-wave heavy-baryon spin wave functions are given by

$$\chi_{\alpha\beta\gamma}^{\Lambda Q} = (\chi^0)_{\alpha\beta}u_\gamma$$

(3)

and

$$\chi_{\alpha\beta\gamma}^{\Sigma Q} = (\chi^1)_{\alpha\beta}\left\{ \frac{1}{\sqrt{3}}\gamma_\mu\gamma_5u_\mu \right\}_\gamma.$$  

(4)
To represent the orbital excitation for P-wave heavy baryon states, one can use the relative momenta $K = \frac{1}{\sqrt{6}}(p_1 + p_2 - 2p_3)$ and $k = \frac{1}{\sqrt{2}}(p_1 - p_2)$, symmetric and antisymmetric respectively under interchange of the constituent light quark momenta $p_1$ and $p_2$. The $\Lambda_{Q1}$ degenerate state spin wave functions can be written as
\[ \chi^\Lambda_{Q1} = (\chi^0 K^\mu)_{\alpha\beta} \left\{ \frac{1}{\sqrt{3}} \gamma^5 u \right\} \gamma^\mu . \tag{5} \]

S-wave and P-wave heavy baryon spin wave functions are summarized in Table (I). The heavy baryon total wave functions are constructed ensuring overall symmetry with respect to $flavour \otimes spin \otimes orbital$.

The one–pion transition amplitudes between heavy baryons can then be written as
\[ M^\pi = \langle \pi(p), B_{Q}(v) | T | B_{Q}(v) \rangle = \bar{\psi}_2^{\mu_1...\mu_{j2}}(v)\psi_1^{\mu_1...\mu_{j1}}(v)M_{\mu_1...\mu_{j1},\nu_1...\nu_{j2}}. \tag{6} \]

The light diquark tensors $M_{\mu_1...\mu_{j1},\nu_1...\nu_{j2}}$ of rank $(j_1 + j_2)$, describe $j_1 \rightarrow j_2 + \pi$ transitions, should have the correct parity and project out the appropriate partial wave amplitude.

HQS predicts that S-wave to S-wave transitions involve two $p$–wave coupling constants. However, each of the single pion transitions from the K-multiplet and from the k-multiplet down to the ground state are determined in terms of seven coupling constants. In fact, there are three $s$–wave and four $d$–wave couplings for each. Matrix elements of these transitions are explicitly given in [I].

To go beyond HQS predictions, we invoke the $SU(6) \otimes O(3)$ symmetry of the light degrees of freedom to calculate the light-side transition matrix elements $M$. In S-wave to S-wave single-pion decays, the transitions involved are $1^+ \rightarrow 0^+$ and $1^+ \rightarrow 1^+$ with light diquark transition tensors given by
\[ M_{\mu_1;\nu_{j2}} = \left( \bar{\phi}_{\nu_{j2}} \right)^{\alpha\beta} \left( O \right)_{\alpha\beta}^{\alpha'\beta'} \left( \phi_{\mu_1} \right)_{\alpha'\beta'}. \tag{7} \]

where the operator $O$ is given in terms of an overlap integral which is unknown. Constraints on the operator $O$ come from parity conservation and from the partial wave involved in the emission process. Since $l_{\pi} = 1$, therefore, it is easy to show that $O$ must be a pseudoscalar operator involving
Table 1: spin wave functions of S-wave and P-wave heavy baryons. The symbol \( \{AB\}^0 \) refers to a traceless symmetric tensor.

| \( j^P \) | \( J^P \) | \( \chi_{\alpha\beta\gamma} \) |
|----------|----------|------------------|
| S-wave states |
| \( \Lambda_Q \) | 0\(^+\) | \( \frac{1}{2} \) | \( (\chi^0)_{\alpha\beta} u_\gamma \) |
| \( \Sigma_Q \) | 1\(^+\) | \( \frac{3}{2} \) | \( (\chi^{1,\mu})_{\alpha\beta} \left\{ \frac{1}{\sqrt{3}} \gamma^\mu \gamma_5 u \right\}_\gamma \) |
| Symmetric P-wave states |
| \( \Lambda_{QK_1} \) | 1\(^-\) | \( \frac{1}{2} \) | \( (\chi^0 K^\mu_\perp)_{\alpha\beta} \left\{ \frac{1}{\sqrt{3}} \gamma^\mu \gamma_5 u \right\}_\gamma \) |
| \( \Sigma_{QK_0} \) | 0\(^-\) | \( \frac{1}{2} \) | \( \frac{1}{\sqrt{3}} (\chi^{1,\mu} K^\mu_\perp)_{\alpha\beta} u_\mu \) |
| \( \Sigma_{QK_1} \) | 1\(^-\) | \( \frac{1}{2} \) | \( \frac{i}{\sqrt{2}} (\varepsilon_{\mu\nu\rho\delta} \chi^{1,\nu} K^\rho_\perp u^\delta)_{\alpha\beta} \left\{ \frac{1}{\sqrt{3}} \gamma^\mu \gamma_5 u \right\}_\gamma \) |
| \( \Sigma_{QK_2} \) | 2\(^-\) | \( \frac{1}{2} \) | \( \frac{1}{\sqrt{10}} \gamma_5 (\chi^{1,\mu_1} K^\mu_2_\perp)_{\alpha\beta} \left\{ \frac{1}{\sqrt{10}} \gamma^\mu \gamma_5 u \right\}_\gamma \) |
| Antisymmetric P-wave states |
| \( \Sigma_{Qk_1} \) | 1\(^-\) | \( \frac{1}{2} \) | \( (\chi^0 k^\mu_\perp)_{\alpha\beta} \left\{ \frac{1}{\sqrt{3}} \gamma^\mu \gamma_5 u \right\}_\gamma \) |
| \( \Lambda_{Qk_0} \) | 0\(^-\) | \( \frac{1}{2} \) | \( \frac{1}{\sqrt{3}} (\chi^{1,\mu} k^\mu_\perp)_{\alpha\beta} u_\gamma \) |
| \( \Lambda_{Qk_1} \) | 1\(^-\) | \( \frac{3}{2} \) | \( \frac{i}{\sqrt{2}} (\varepsilon_{\mu\nu\rho\delta} \chi^{1,\nu} k^\rho_\perp u^\delta)_{\alpha\beta} \left\{ \frac{1}{\sqrt{3}} \gamma^\mu \gamma_5 u \right\}_\gamma \) |
| \( \Lambda_{Qk_2} \) | 2\(^-\) | \( \frac{3}{2} \) | \( \frac{1}{\sqrt{10}} \gamma_5 (\chi^{1,\mu_1} k^\mu_2_\perp)_{\alpha\beta} \left\{ \frac{1}{\sqrt{10}} \gamma^\mu \gamma_5 u \right\}_\gamma \) |
one power of the pion momentum $p$. In the constituent quark model the pion is emitted by one of the light quarks, hence, the transition operator $O$ must be a one-body operator. Possible two-body emission operators are non leading in large-$N_C$ \cite{9} and are thus neglected in the constituent quark model approach \cite{10}. One then has the unique operator

$$\langle p | O | \rangle_{\alpha \beta}^{\alpha' \beta'} = \frac{1}{2} \left( (\gamma^\sigma \gamma_5)^{\alpha} \otimes (\bar{\pi} \beta') + (\bar{\pi} \alpha') \otimes (\gamma^\sigma \gamma_5)^{\beta} \right) f_p p_\perp^\sigma$$  \hspace{1cm} (8)

The relevant transition tensors for P-wave to S-wave single-pion decays, which involve $1^- \rightarrow \{0^+, 1^+\}$, $0^- \rightarrow 0^+$ and $2^- \rightarrow \{0^+, 1^+\}$, are given by

$$M_{\mu_1 \cdots \mu_1 \nu_{j_2}} = \sum_{l_\pi = 0, 2} \langle \bar{\phi}(\nu_{j_2}) \rangle^{\alpha \beta} \left( O(l_\pi) \right)_{\alpha \beta}^{\alpha' \beta'} \langle \phi(\lambda) \rangle_{\alpha \beta}^{\alpha' \beta'}$$ \hspace{1cm} (9)

the appropriate operators for these transitions are given by

$$\langle O(\lambda) | p \rangle_{\alpha \beta}^{\alpha' \beta'} = \frac{1}{2} \left( (\gamma^\sigma \gamma_5)^{\alpha} \otimes (\bar{\pi} \beta') \pm (\bar{\pi} \alpha') \otimes (\gamma^\sigma \gamma_5)^{\beta} \right) (f_s g_{s \lambda} + f_d P_{s \lambda}),$$  \hspace{1cm} (10)

with, $P_{s \lambda}(p) = p_{\perp, \sigma} p_{\perp, \lambda} - \frac{1}{3} p_\perp^2 g_{s \lambda} \cdot$ The plus sign has to be used for transitions from the Symmetric (K-multiplet) and the minus one for transitions from the Antisymmetric (k-multiplet). P-wave to P-wave transitions were analyzed in \cite{9} and the generalization to transitions involving higher orbital excitations is straightforward.

The matrix elements, Eq. (7) and Eq. (8), of the operators Eq. (9) and Eq. (10), can be readily evaluated using the light diquark spin wave functions in Table(1). The two couplings of the ground state transitions are not independent. They are, actually, related to the single p-wave coupling $f_p$ by

$$f_p^1 = - f_p^2 = f_p.$$  \hspace{1cm} (11)

Using PCAC the coupling constant $f_p$ can be related to the axial vector current coupling strength $g_A$, one obtains $f_p = g_A / f_\pi$.

For P-wave (K-multiplet) to S-wave transitions, the evaluation of the matrix elements leads to the following relations

$$f_s^{1(K)} = f_s; \hspace{1cm} f_s^{2(K)} = - \sqrt{3} f_s; \hspace{1cm} f_s^{3(K)} = \sqrt{2} f_s$$  \hspace{1cm} (12)

$$f_d^{1(K)} = f_d; \hspace{1cm} f_d^{2(K)} = - \frac{1}{\sqrt{2}} f_d; \hspace{1cm} f_d^{3(K)} = - f_d; \hspace{1cm} f_d^{4(K)} = f_d.$$  \hspace{1cm} (13)
The number of independent coupling constants, therefore, has been reduced from seven to the two constituent quark model s-wave and d-wave coupling factors $f_s$ and $f_d$. Similar relations, with two different couplings, hold for transitions from the P-wave (k-multiplet) to S-wave.

The first important conclusion we have reached so far is that, S-wave to S-wave and P-wave (K-multiplet) to S-wave single pion transitions are given in terms of the three independent couplings $f_p$, $f_s$ and $f_d$. For charmed baryons, they can be identified by the three strong couplings $g_{\Sigma c\Lambda c\pi}$, $f_{\Lambda c1\Sigma c\pi}$ and $f_{\Lambda c*1\Sigma c\pi}$ respectively. We would like to mention that, after taking into account the different normalizations, the results Eqs. (11) and (12–13) are in agreement with corresponding results using HHCPT [7].

The three independent couplings can be written in terms of Light-Front (LF) [12] matrix elements of the strong transition current $\hat{j}_\pi(q)$ between LF heavy baryon helicity states. Working in the Drell-Yan frame, we get [13]

$$g_{\Sigma c\Lambda c\pi} = -\frac{2\sqrt{3}M_{\Lambda c}M_{\Sigma c}}{(M_{\Sigma c}^2 - M_{\Lambda c}^2)} \langle \Lambda(P', \uparrow) | \hat{j}_\pi(0) | \Sigma(P, \uparrow) \rangle,$$

and

$$f_{\Lambda c1\Sigma c\pi} = \langle \Sigma(P', \uparrow) | \hat{j}_\pi(0) | \Lambda c1(P, \uparrow) \rangle,$$

In the LF formalism the total baryon spin-momentum distribution function can be written in the following general form

$$\Psi(x_i, p_{\perp i}, \lambda_i; \lambda) = \chi(x_i, p_{\perp i}, \lambda_i; \lambda) \psi(x_i, p_{\perp i}).$$

Here, $\chi(x_i, p_{\perp i}, \lambda_i; \lambda)$ and $\psi(x_i, p_{\perp i})$ represent the spin and momentum distribution functions respectively. Assuming factorization of longitudinal and transverse momentum distribution functions, one can write

$$\psi(x_i, p_{\perp i}) = \prod_{i=1}^{3} \delta(x_i - \bar{x}_i) \exp \left[ -\frac{\vec{k}^2}{2\alpha_\rho^2} - \frac{\vec{K}^2}{2\alpha_\lambda^2} \right].$$

The longitudinal momentum distribution functions are approximated by Dirac-delta functions which are peaked at the constituent quark longitudinal momenta mean values $\bar{x}_i = \frac{m_i}{M}$. This assumption is justified since in the weak
binding \textsuperscript{[14]} and the valence \textsuperscript{[13]} approximations, the constituent quarks are moving with the same velocity inside the baryon. The heavy baryons spin wave functions, which are the LF generalization of the conventional constituent quark model spin-isospin functions, are explicitly given by \textsuperscript{[13]}

\[ \chi^\Lambda_{Q}(x, p_{\perp}, \lambda; \lambda) = \bar{u}(p_1, \lambda_1) \left[ (P + M_{\Delta}) \gamma_5 \right] \nu(p_2, \lambda_2) \bar{u}(p_3, \lambda_3) u(P, \lambda). \quad (19) \]

For the $\Sigma_{Q}$-like baryons, one has

\[ \chi^{\Sigma_{Q}}(x, p_{\perp}, \lambda; \lambda) = \bar{u}(p_1, \lambda_1) \left[ (P + M_{\Lambda}) \gamma_5 \right] \nu(p_2, \lambda_2) \bar{u}(p_3, \lambda_3) \gamma_{\perp} \gamma_5 u(P, \lambda), \quad (20) \]

The excited states $\Lambda_{Q1}$, with $J^P = \frac{1}{2}^-$, and $\Lambda_{Q1}^*$, with $J^P = \frac{3}{2}^-$, have spin functions of the forms

\[ \chi^{\Lambda_{Q1}}(x, p_{\perp}, \lambda; \lambda) = \bar{u}(p_1, \lambda_1) \left[ (P + M_{\Lambda_{c1}}) \gamma_5 \right] \nu(p_2, \lambda_2) \bar{u}(p_3, \lambda_3) K \gamma_5 u(P, \lambda), \]

\[ \chi^{\Lambda_{Q1}}(x, p_{\perp}, \lambda; \lambda) = \bar{u}(p_1, \lambda_1) \left[ (P + M_{\Lambda_{c1}^*}) \gamma_5 \right] \nu(p_2, \lambda_2) \bar{u}(p_3, \lambda_3) K_{\mu} u^\mu(P, \lambda). \quad (21) \]

The three charmed baryons strong couplings $g_{\Sigma_{c} \Lambda_{c} \pi}$, $f_{\Lambda_{c1} \Sigma_{c} \pi}$ and $f_{\Lambda_{c1}^* \Sigma_{c} \pi}$ are calculated \textsuperscript{[1]} to be

\[ g_{\Sigma_{c} \Lambda_{c} \pi} = 6.81 \text{ GeV}^{-1}, \quad f_{\Lambda_{c1} \Sigma_{c} \pi} = 1.16, \quad f_{\Lambda_{c1}^* \Sigma_{c} \pi} = 0.96 \times 10^{-4} \text{ MeV}^{-2}. \quad (22) \]

These values can be used to determine the corresponding HHCPT couplings, one gets

\[ g_2 = 0.52, \quad h_2 = 0.54, \quad h_8 = 3.33 \times 10^{-3} \text{ MeV}^{-1}. \quad (23) \]

Assuming that the width of $\Sigma_{c}$, $\Lambda_{c1}$ and $\Lambda_{c1}^*$ are saturated by strong decay channels one can estimate the values of the three couplings using the experimental decay rates. CLEO \textsuperscript{[16]} results for $\Gamma_{\Sigma_{c}^{++} \rightarrow \Lambda_{c1}^{+} \pi^+} = 17.9^{+3.8}_{-3.2}$ MeV and $\Gamma_{\Sigma_{c}^{0} \rightarrow \Lambda_{c1}^+ \pi^-} = 13.0^{+3.7}_{-3.0}$ MeV can be used to determine the coupling $g_{\Sigma_{c} \Lambda_{c} \pi}$. One, therefore, respectively gets

\[ g_{\Sigma_{c} \Lambda_{c} \pi} = 8.03^{+1.97}_{-1.92} \text{ GeV}^{-1}. \quad (25) \]

\textsuperscript{2} The numerical values for the constituent quark masses and the oscillator couplings are taken to be $m_u = m_d = 0.33$ GeV, $m_c = 1.51$ GeV, $\alpha_p = 0.40$ GeV/c and $\alpha_\lambda = 0.52$ GeV/c. The charmed baryon masses will be taken from Table 1 of \textsuperscript{[8]}.\]
and

\[ g_{\Sigma \Lambda_c \pi} = 6.97^{+1.84}_{-1.74} \text{GeV}^{-1} \]  

To estimate \( f_{\Lambda_c \Sigma \pi} \) we use the Particle Data Group [17] average value for \( \Lambda_c (2593) \) width \( (\Gamma_{\Lambda_c (2593)} = 3.6^{+2.0}_{-1.3} \text{MeV}) \) to obtain

\[ f_{\Lambda_c \Sigma \pi} = 1.11^{+0.31}_{-0.20}. \]  

Finally, taking the upper bound on the \( \Lambda_c^+ (2625) \) width obtained by CLEO [16] \( (\Gamma_{\Lambda_c^+ (2625)} < 1.9 \text{MeV}) \) one gets

\[ f_{\Lambda_c^+ \Sigma \pi} = 1.66 \times 10^{-4} \text{MeV}^{-2}. \]

The LF quark model predictions for the numerical values of the single-pion couplings Eq. (23) are in good agreement with estimates obtained using the available experimental data Eqs. (25-28).

We are now in a position to predict charmed baryons strong decay rates using the general formula

\[ \Gamma = \frac{1}{2 J_1 + 1} \frac{| \vec{q} |}{8 \pi M_{BQ}^2} \sum_{spins} | M_\pi |^2, \]

with \( | \vec{q} | \) being the pion momentum in the rest frame of the decaying baryon. The numerical values for S-wave to S-wave and P-wave (K-multiplet) to S-wave single pion decay rates and the updated experimental values of the Review of Particle Physics [17] are summarized in Table 2. To predict the total decay width of these states, one has to include decay rates for the two-pion transitions reported by [7]. Table 2 shows that most of the predicted decay widths agree quite well or they are within the range of the corresponding experimental data. We, also, notice that the \( \Sigma_c (2760) \), \( \Sigma_c (2770) \) and \( \Sigma_c (2800) \) widths are relatively broad and it might be difficult to measure them experimentally.

To summarize, we have used the \( SU(2N_f) \times O(3) \) symmetry, of the light diquark system, to reduce the number of HQS coupling factors of heavy baryon single-pion decays. These result, which are obtained using covariant spin wave functions for the light diquark system, agree with the HHCPT [7]. We also calculated the three independent couplings \( g_{\Sigma_c \Lambda_c \pi}, f_{\Lambda_c \Sigma_c \pi} \) and \( f_{\Lambda_c^+ \Sigma_c \pi} \) using a Light-Front (LF) quark model functions. Most of the predicted decay rates agree with the available experimental data. Like other models, our numerical result will depend on the values of the the constituent quark masses and the harmonic oscillator constants \( \alpha_p \) and \( \alpha_\lambda \) which are free parameters.
Table 2: Decay rates for charmed baryon states.

| $B_Q \rightarrow B'_Q \pi$ | $\Gamma$ (MeV) | $\Gamma_{\text{expt.}}$ (MeV) |
|---------------------------|----------------|-------------------------------|
| **Ground state transitions** |                |                               |
| $\Sigma^+_c \rightarrow \Lambda_c \pi^0$ | 1.70 |                   |
| $\Sigma^0_c \rightarrow \Lambda_c \pi^-$ | 1.57 |                   |
| $\Sigma^{++}_c \rightarrow \Lambda_c \pi^+$ | 1.64 |                   |
| $\Sigma^{*0}_c \rightarrow \Lambda_c \pi^-$ | 12.40 | $13.0^{+3.7}_{-3.0}$ |
| $\Sigma^{*+}_c \rightarrow \Lambda_c \pi^+$ | 12.84 | $17.9^{+3.8}_{-3.2}$ |
| $\Xi^{*0}_c \rightarrow \Xi^{0}_c \pi^0$ | 0.72 | $< 5.5$ |
| $\Xi^{*0}_c \rightarrow \Xi^{+}_c \pi^-$ | 1.16 |                   |
| $\Xi^{*+}_c \rightarrow \Xi^{0}_c \pi^+$ | 1.12 | $< 3.1$ |
| $\Xi^{*+}_c \rightarrow \Xi^{*+}_c \pi^0$ | 0.69 |                   |
| **P-wave to S-wave transitions** | |                               |
| $\Lambda_{c1}(2593) \rightarrow \Sigma^0_c \pi^+$ | 2.61 | $3.6^{+2.0}_{-1.3}$ |
| $\Lambda_{c1}(2593) \rightarrow \Sigma^+_c \pi^0$ | 1.73 |                   |
| $\Lambda_{c1}(2593) \rightarrow \Sigma^{++}_c \pi^-$ | 2.15 |                   |
| $\Lambda^*_{c1}(2625) \rightarrow \Sigma^0_c \pi^+$ | 0.77 | $\Gamma_{\Lambda^*_{c1}} < 1.9$ |
| $\Lambda^*_{c1}(2625) \rightarrow \Sigma^+_c \pi^0$ | 0.69 |                   |
| $\Lambda^*_{c1}(2625) \rightarrow \Sigma^{++}_c \pi^-$ | 0.73 |                   |
| $\Xi^*_{c1}(2815) \rightarrow \Xi^0_c \pi^+$ | 4.84 | $\Gamma_{\Xi^*_{c1}} < 2.4$ |
| $\Xi^*_{c1}(2815) \rightarrow \Xi^{*+}_c \pi^0$ | 2.38 |                   |
| $\Xi^*_{c1}(2815) \rightarrow \Xi^{*0}_c \pi^+$ | 0.30 |                   |
| $\Xi^*_{c1}(2815) \rightarrow \Xi^{*+}_c \pi^-0$ | 0.15 |                   |
| $\Sigma_{c0}(2760) \rightarrow \Lambda_c \pi$ | 110.36 |                   |
| $\Sigma_{c1}(2770) \rightarrow \Sigma_c \pi$ | 50.92 |                   |
| $\Sigma_{c2}(2800) \rightarrow \Sigma^{*+}_c \pi$ | 50.21 |                   |
Acknowledgments

One of us S. T. would like to thank Patrick J. O’Donnell and the Department of Physics, University of Toronto for hospitality. This research was supported in part by the National Sciences and Engineering Research Council of Canada.

References

[1] F. Hussain, G. Thompson J.G. Körner, preprint IC/93/314, MZ-TH/93-23 and hep-ph/9311309, to appear in the proceedings of the 6th. Regional Conference in Mathematical Physics, Islamabad, February 1994.

[2] J.G. Körner, M. Krämer and D. Pirjol, Progr. Part. Nucl. Phys., Vol. 33 (1994) 787.

[3] F. Hussain, J.G. Körner, J. Landgraf and Salam Tawfiq, Z. Phys. C69 (1996) 655.

[4] F. Hussain, J.G. Körner and Salam Tawfiq, ICTP preprint, IC/96/35 and Mainz preprint MZ-TH/96-10, 1996.

[5] P. Cho, Nucl.Phys. B396(1993)183; Phys. Rev. D50 (1994)3295.

[6] M-Q Huang, Y-B Dai and C-S Huang, Phys. Rev. D52 (1995) 3986.

[7] D. Pirjol and T. M. Yan, Phys. Rev. D56(1997)5483.

[8] G. Chiladze and A. Falk, Phys. Rev. D56(1997)6738.

[9] E. Witten, Nucl.Phys. B223(1983)483; C. Carone, H. Georgi and S. Osofski, Phys. Lett. 322B(1994)483; M. Luty and J. March-Russel, Nucl. Phys. B246(1994)71; R. F. Dashen, E. Jenkins and A. V. Manohar, Phys. Rev. D49(1994)4713; R. F. Dashen, E. Jenkins and A.V.Manohar, Phys. Rev. D51(1995)3697.

[10] C. Carone, H. Georgi, L. Kaplan and D. Morin, Phys. Rev. D50(1994)5793.
[11] T. M. Yan et. al., Phys. Rev. D46 (1992)1148; Erratum, to be published.

[12] For a recent review and references see S. J. Brodsky, H-S Pauli and S. S. Pinsky, hep-ph/9705477, 1997c.

[13] Salam Tawfiq, Patrick J. O’Donnell and J.G. Körner, hep-ph/9803246, University of Toronto preprint UTPT-98-03 and Mainz preprint MZ-TH/98-08, 1998, to appear in Phys. Rev. D.

[14] F. Hussain, J.G. Körner and G. Thompson, Ann. Phys. C59(1993)334.

[15] Z. Dziembowski, Phys. Rev D37(1988)778; H. J. Weber, Phys. Lett B209(1988)425; Z. Dziembowski and H. J. Weber, Phys. Rev D37(1988)1289; W. Konen and H. J. Weber, Phys. Rev. D41(1990)2201.

[16] G. Brandenburg et.al., CLEO Coll., Phys. Rev. Lett 78(1997)2304; L. Gibbons et.al., CLEO Coll., Phys. Rev. Lett 77(1996)810; P. L. Frabetti et.al, E687 Coll., Phys. Lett B365(1996)461; Phys. Rev. Lett. 72 (1994) 961; K. W. Edwards et.al., CLEO Coll., Phys. Rev. Lett. 74 (1995) 3331; P. Avery, el.al., CLEO Coll., Phys. Rev. Lett. 75 (1995) 4364; H. Albrecht et.al., ARGUS Coll., Phys. Lett. B317 (1993) 227.

[17] R. M. Barnett et.al., Phys. Rev. D54 (1996)1 and 1997 off-year partial updated for the 1998 edition, http://pdg.lbl.gov/.