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FCNC Transition of Σ_Q to Nucleon

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The loop level flavor changing neutral current transitions of the $\Sigma_b \to n\, l^+ l^-$ and $\Sigma_c \to p\, l^+ l^-$ are investigated in full QCD and heavy quark effective theory in the light cone QCD sum rules approach. Using the most general form of the interpolating current for Σ_Q, $Q = b$ or c, the transition form factors are calculated using two sets of input parameters entering the nucleon distribution amplitudes. The obtained results are used to estimate the decay rates of the corresponding transitions.

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1. Introduction

The $\Sigma_b \to n\, l^+l^-$ and $\Sigma_c \to p\, l^+l^-$ are governed by flavor changing neutral currents (FCNC) transitions of $b \to d$ and $c \to u$, respectively. These transitions are described via electroweak penguin and weak box diagrams in the standard model (SM) and they are sensitive to new physics. Looking for SUSY particles, light dark matter and also probable fourth generation of the quarks is possible by investigating such loop level transitions. This transitions are also good framework for reliable determination of the V_{tb}, V_{td}, V_{cb}, and V_{bu} as members of the CKM matrix, CP and T violations and polarization asymmetries.

In the present work, we calculate all twelve form factors entering the semileptonic $\Sigma_b \to n\, l^+l^-$ and $\Sigma_c \to p\, l^+l^-$ transitions using the light cone QCD sum rules in full as well as heavy quark effective theory (HQET). We use the value of the eight independent parameters entering the nucleon DA's from two different sources: predicted by QCD sum rules and obtained via lattice QCD. Using the obtained form factors, we predict the corresponding transition rates. For details, see the original work [1].

2. Theoretical Framework

At quark level, the considered decays proceed via loop $b\ (c) \to d\ (u)$ transition and can be described by the following electroweak penguin and weak box diagrams and corresponding effective Hamiltonian:

$$\begin{aligned}\mathscr{H}_{eff} = & \frac{G_F\ \alpha V_{Q'Q}\ V^*_{Q'q}}{2\sqrt{2}\,\pi}\Big\{C_9^{eff}\ \bar{q}\gamma_\mu(1-\gamma_5)Q\bar{l}\gamma^\mu l + C_{10}\ \bar{q}\gamma_\mu(1-\gamma_5)Q\bar{l}\gamma^\mu\gamma_5 l \\ & -\ 2m_Q\,C_7\frac{1}{q^2}\ \bar{q}i\sigma_{\mu\nu}q^\nu(1+\gamma_5)Q\bar{l}\gamma^\mu l\Big\},\end{aligned} \tag{2.1}$$

where, Q' refers to the $u,\ c,\ t$ for bottom case and $d,\ s\ ,b$ for charm case, respectively. The main contributions come from the heavy quarks, so we will consider $Q'=t$ and $Q'=b$ respectively for the $\Sigma_b \to n\ l^+l^-$ and $\Sigma_c \to p\ l^+l^-$ transitions. The amplitude of the considered transitions can be obtained by sandwiching the above Hamiltonian between the initial and final states. To proceed, we need to know the matrix elements $\langle N|J_\mu^{tr,I}|\Sigma_Q\rangle$ and $\langle N|J_\mu^{tr,II}|\Sigma_Q\rangle$, where $J_\mu^{tr,I}(x) = \bar{q}(x)\gamma_\mu(1-\gamma_5)Q(x)$ and $J_\mu^{tr,II}(x) = \bar{q}(x)i\sigma_{\mu\nu}q^\nu(1+\gamma_5)Q(x)$ are transition currents entering to the Hamiltonian. In full theory, these matrix elements are parameterized in terms of twelve transition form factors, f_i, g_i, f_i^T and g_i^T with $i=1\to 3$ by the following way:

$$\begin{aligned}\langle N(p)\mid J_\mu^{tr,I}(x)\mid \Sigma_Q(p+q)\rangle = & \bar{N}(p)\big[\gamma_\mu f_1(Q^2) + i\sigma_{\mu\nu}q^\nu f_2(Q^2) + q^\mu f_3(Q^2) - \gamma_\mu\gamma_5 g_1(Q^2) \\ & -\ i\sigma_{\mu\nu}\gamma_5 q^\nu g_2(Q^2) - q^\mu\gamma_5 g_3(Q^2)\big]\, u_{\Sigma_Q}(p+q),\end{aligned} \tag{2.2}$$

and,

$$\langle N(p)\mid J_\mu^{tr,II}(x)\mid \Sigma_Q(p+q)\rangle = \bar{N}(p)\big[\gamma_\mu f_1^T(Q^2) + i\sigma_{\mu\nu}q^\nu f_2^T(Q^2) + q^\mu f_3^T(Q^2) + \gamma_\mu\gamma_5 g_1^T(Q^2)$$

$$+ \, i\sigma_{\mu\nu}\gamma_5 q^\nu g_2^T(Q^2) + q^\mu \gamma_5 g_3^T(Q^2)\Big] u_{\Sigma_Q}(p+q), \tag{2.3}$$

where $Q^2 = -q^2$. Here, $N(p)$ and $u_{\Sigma_Q}(p+q)$ are the spinors of nucleon and Σ_Q, respectively. In HQET, where $m_Q \to \infty$, the number of independent form factors is reduced to two (see [1]).

To obtain sum rules for the form factors, we start considering the following correlation functions:

$$\Pi^I_\mu(p,q) = i\int d^4x e^{iqx}\langle N(p) \mid T\{J^{tr,I}_\mu(x)\bar{J}^{\Sigma_Q}(0)\} \mid 0\rangle,$$
$$\Pi^{II}_\mu(p,q) = i\int d^4x e^{iqx}\langle N(p) \mid T\{J^{tr,II}_\mu(x)\bar{J}^{\Sigma_Q}(0)\} \mid 0\rangle, \tag{2.4}$$

where, p denotes the proton (neutron) momentum and q is the transferred momentum. The J^{Σ_Q} which is interpolating current of Σ_Q baryon is given as:

$$J^{\Sigma_Q}(x) = \frac{-1}{\sqrt{2}}\varepsilon^{abc}\Big[\Big\{q_1^{Ta}(x)CQ^b(x)\Big\}\gamma_5 q_2^c(x) - \Big\{Q^{Ta}(x)Cq_2^b(x)\Big\}\gamma_5 q_1^c(x)$$
$$+\beta\Big\{\{q_1^{Ta}(x)C\gamma_5 Q^b(x)\}q_2^c(x) - \{Q^{Ta}(x)C\gamma_5 q_2^b(x)\}q_1^c(x)\Big\}\Big], \tag{2.5}$$

where, C is the charge conjugation operator and β is an arbitrary parameter with $\beta = -1$ corresponding to the Ioffe current, q_1 and q_2 are the u and d quarks, respectively and a, b, c are the color indices.

The main idea in QCD sum rules is to calculate the aforementioned correlation functions in two different ways:

- From phenomenological or physical side, they are calculated in terms of the hadronic parameters via saturating them with a tower of hadrons with the same quantum numbers as the interpolating currents.
- In theoretical side, the time ordering product of the initial state and transition current is expanded in terms of nucleon distribution amplitudes having different twists via the operator product expansion (OPE) at deep Euclidean region. By OPE the short and large distance effects are separated. The short distance contribution is calculated using the perturbation theory, while the long distance phenomena are parameterized in terms of nucleon DA's.

To get the sum rules for the form factors, the two above representations of the correlation functions are equated through the dispersion relation. To suppress the contribution of the higher states and continuum and isolate the ground state, the Borel transformation as well as continuum subtraction are applied to both sides of the sum rules.

3. Numerical results

This section is devoted to the numerical analysis of the form factors as well as the total decay rate for $\Sigma_b \longrightarrow n\ell^+\ell^-$ and $\Sigma_c \longrightarrow p\ell^+\ell^-$ transitions in both full theory and HQET limit.

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In obtaining numerical values, we use the following inputs for masses and quark condensates: $\langle \bar{u}u\rangle(1\ GeV) = \langle \bar{d}d\rangle(1\ GeV) = -(0.243)^3\ GeV^3$, $m_n = 0.939\ GeV$, $m_p = 0.938\ GeV$, $m_b = 4.7\,GeV$, $m_c = 1.23\,GeV$, $m_{\Sigma_b} = 5.805\,GeV$, $m_{\Sigma_c} = 2.4529\,GeV$ and $m_0^2(1\,GeV) = (0.8\pm 0.2)\,GeV^2$. The sum rules expressions for the form factors contain the nucleon DA's as the main input parameters. These DA's include also eight independent parameters, namely, f_N, λ_1, λ_2, V_1^d, A_1^u, f_1^d, f_1^u and f_2^d. All of these parameters have been calculated in the framework of the light cone QCD sum rules (set 1) and most of them are now available in lattice QCD. In the following, we will also denote the lattice QCD input parameters by set2.

The next step is to derive the behavior of the form factors in terms of the q^2. The sum rules predictions for the form factors are not reliable in the whole physical region. To be able to extend the results for the form factors to the whole physical region, we look for a parametrization of the form factors such that in the reliable region which is approximately 1 GeV below the perturbative cut, the original form factors and their fit parametrization coincide each other. Our numerical results lead to the following extrapolation for the form factors in terms of q^2:

$$f_i(q^2)[g_i(q^2)] = \frac{a}{(1-\frac{q^2}{m_{fit}^2})} + \frac{b}{(1-\frac{q^2}{m_{fit}^2})^2}, \tag{3.1}$$

where, the fit parameters a, b and m_{fit} in full theory and HQET limit are presented in [1]. Using these form factors, we calculate the total decay rates in the full allowed physical region, namely, $4m_l^2 \leq q^2 \leq (m_{\Sigma_{b,c}} - m_{n,p})^2$. The results for decay rates are shown in Tables 1 and 2. From these

	$\Sigma_b \longrightarrow ne^+e^-$	$\Sigma_b \longrightarrow n\mu^+\mu^-$	$\Sigma_b \longrightarrow n\tau^+\tau^-$
Full (set1)	$(4.26\pm 1.27)\times 10^{-20}$	$(2.08\pm 0.70)\times 10^{-20}$	$(1.0\pm 0.3)\times 10^{-22}$
Full (set2)	$(5.4\pm 1.6)\times 10^{-21}$	$(2.64\pm 0.79)\times 10^{-21}$	$(4.01\pm 1.25)\times 10^{-23}$
HQET(set1)	$(8.20\pm 3.04)\times 10^{-20}$	$(4.25\pm 2.07)\times 10^{-20}$	$(6.26\pm 2.46)\times 10^{-22}$
HQET(set2)	$(1.10\pm 0.33)\times 10^{-20}$	$(5.67\pm 1.73)\times 10^{-21}$	$(1.16\pm 0.46)\times 10^{-22}$

Table 1: Values of the $\Gamma(\Sigma_b \longrightarrow n\ \ell^+\ell^-)$ in GeV for different leptons and two sets of input parameters.

	$\Sigma_c \longrightarrow pe^+e^-$	$\Sigma_c \longrightarrow p\mu^+\mu^-$
Full (set1)	$(5.59\pm 1.78)\times 10^{-25}$	$(9.7\pm 2.7)\times 10^{-26}$
Full (set2)	$(1.35\pm 0.35)\times 10^{-25}$	$(2.36\pm 0.80)\times 10^{-26}$
HQET(set1)	$(7.99\pm 3.07)\times 10^{-25}$	$(1.50\pm 0.58)\times 10^{-25}$
HQET(set2)	$(2.50\pm 0.81)\times 10^{-25}$	$(4.30\pm 1.36)\times 10^{-26}$

Table 2: Values of the $\Gamma(\Sigma_c \longrightarrow p\ \ell^+\ell^-)$ in GeV for different leptons and two sets of input parameters.

tables, we see that: a) The value of the decay rate decreases by increasing in the lepton mass. This is reasonable since the phase space in for example τ case is smaller than that of the electron and μ cases. b) The order of magnitude on decay rate of bottom case shows the possibility of the experimental studies on the $\Sigma_b \longrightarrow n\ \ell^+\ell^-$ transition, specially the μ case, at LHC. The lifetime of the Σ_b is not exactly known yet, but if we consider its lifetime approximately the same order of the b-baryon admixture $(\Lambda_b, \Xi_b, \Sigma_b, \Omega_b)$ lifetime, which is $\tau = (1.319^{+0.039}_{0.038}) \times 10^{-12}\ s$, the branching fraction is obtained in 10^{-7} order. Any measurements in this respect and comparison of the results with the predictions of the present work can give essential information about the nature of the Σ_Q baryon, nucleon distribution amplitudes and search for the new physics beyond the standard model.

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References

[1] K. Azizi, M. Bayar , M. T. Zeyrek, *Flavor Changing Neutral Currents Transition of the Σ_Q to Nucleon in Full QCD and Heavy Quark Effective Theory, J. Phys.G 37, 085002 (2010), arXiv:0910.4521 [hep-ph].*