Chapter 16
Decay $D_s^+ \to K^{(*)0}\ell^+\nu_\ell$ in Covariant Quark Model

N. R. Soni and J. N. Pandya

Abstract Semileptonic decay widths of D_s^+ mesons ($D_s^+ \to K^{(*)0}\ell^+\nu_\ell$) are presented. The required transition form factors are computed in the entire physical range of momentum transfer in the framework of covariant quark model (CQM). We compute the branching fractions incorporating the form factors and obtain the ratio of the partial decay width $\Gamma(D_s^+ \to K^0\mu^+\nu_\mu)/\Gamma(D_s^+ \to K^0 e^+\nu_e) = 0.98$ which is in close resemblance with isospin symmetry.

16.1 Introduction

The semileptonic decays of charmed mesons provide the best tool in exploring the key aspects of heavy quark decays and heavy-light meson spectroscopy. The semileptonic decays are important to study because they provide insight into the quark flavor mixing and hence the elements of Cabibbo Kobayashi Maskawa (CKM) matrix.

In this paper, we compute the semileptonic branching fractions of charmed mesons in the frame work of covariant quark model (CQM) developed by Efimov and Ivanov [1–4]. The CQM is the effective field theoretical approach for the hadronic interactions with their constituents. The exclusive semileptonic branching fraction of D_s^+ mesons are reported in [5] using the CLEO-c data from e^+e^- annihilations at Cornell Electron Storage Ring. These decays are also studied in light front quark model (LFQM) [6] and heavy meson chiral theory (HMχT) [7].

N. R. Soni · J. N. Pandya (✉)
Applied Physics Department, Faculty of Technology and Engineering,
The Maharaja Sayajirao University of Baroda, Vadodara 390001, Gujarat, India
e-mail: jnpandya-apphy@msubaroda.ac.in

N. R. Soni
e-mail: nrsoni-apphy@msubaroda.ac.in

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16.2 Form Factors and Branching Fractions

For the channel $D_s^+ \to K^{(*)0}\ell^+\nu_\ell$, the matrix element can be written as

$$\mathcal{M}(D_s^+ \to K^{(*)0}\ell^+\nu_\ell) = \frac{G_F}{\sqrt{2}} V_{cd} \langle K^{(*)0}|\bar{s}O^\mu c|D_s^+\rangle \ell^+ O^\mu \nu_\ell \qquad (16.1)$$

where G_F and O^μ is the fermi coupling constant and weak Dirac matrix respectively. The invariant form factors for D_s^+ decays into K^0 and $K^*(892)^0$ can be written as

$$\mathcal{M}^\mu_{D_s^+\to K^0} = P^\mu F_+(q^2) + q^\mu F_-(q^2) \qquad (16.2)$$

and

$$\mathcal{M}^\mu_{D_s^+\to K^{*0}} = \frac{1}{m_1+m_2}\varepsilon_\nu^\dagger\{-g^{\mu\nu}Pq A_0(q^2) + P^\mu P^\nu A_+(q^2) + q^\mu P^\nu A_-(q^2) + i\epsilon^{\mu\nu\alpha\beta}P_\alpha q_\beta V(q^2)\}. \qquad (16.3)$$

where $P = p_1 + p_2$ and $q = p_1 - p_2$ with p_1, p_2 to be the momenta of D_s^+ and $K^{(*)0}$ mesons respectively. The form factors $F_\pm$, V, A_0, $A_\pm$ are computed in the framework of CQM in the whole physical range of momentum transfer. The invariant form factors are expressed in terms of helicity form factors in the following way:

For $D_s^+ \to K^0$ channel:

$$H_t = \frac{1}{\sqrt{q^2}}(PqF_+ + q^2F_-),$$
$$H_\pm = 0 \quad \text{and} \quad H_0 = \frac{2m_1|\mathbf{p_2}|}{\sqrt{q^2}}F_+ \qquad (16.4)$$

For $D_s^+ \to K^{(*)0}$ channel:

$$H_t = \frac{1}{m_1+m_2}\frac{m_1|\mathbf{p_2}|}{m_2\sqrt{q^2}}\left((m_1^2 - m_2^2)(A_+ - A_-) + q^2A_-\right)$$
$$H_\pm = \frac{1}{m_1+m_2}(-(m_1^2 - m_2^2)A_0 \pm 2m_1|\mathbf{p_2}|V)$$
$$H_0 = \frac{1}{m_1+m_2}\frac{1}{2m_2\sqrt{q^2}}(-(m_1^2 - m_2^2)(m_1^2 - m_2^2 - q^2)A_0 + 4m_1^2|\mathbf{p_2}|^2A_+). \qquad (16.5)$$

where $|\mathbf{p_2}| = \lambda^{1/2}(m^2_{D_s^+}, m^2_{K^{(*)0}}, q^2)/2m_{D_s^+}$ is the momentum of the $K^{(*)0}$ meson in the rest frame of D_s^+ meson. Also $m_1 = m_{D_s^+}$ and $m_2 = m_{K^{(*)0}}$. The form factors are used in computing the semileptonic branching fractions. The relations reads [8]

$$\frac{d\Gamma(D_s^+ \to K^{(0)*}\ell^+\nu_\ell)}{dq^2} = \frac{G_F^2|V_{cd}|^2|\mathbf{p_2}|q^2v^2}{12(2\pi)^3 m_{D_s^+}^2}((1+\delta_\ell)(\mathcal{H}_U + \mathcal{H}_L) + 3\delta_\ell\mathcal{H}_S) \tag{16.6}$$

where δ_ℓ is the helicity flip factor, v is the velocity type parameter and $\mathcal{H}$'s are the bilinear combination of the helicity structure functions. The detailed description of the helicity amplitudes are given in [9–11].

16.3 Results

The necessary numerical computational techniques and the model parameters are given in the recent paper [12, 13] and references therein. The other model independent parameters such as meson masses, life-time of D_s^+ meson, Fermi coupling constant and CKM matrices are taken from PDG [14]. The form factors (16.2) and (16.3) are computed in the entire physical range of momentum transfer $0 \le q^2 \le q^2_{max} = (m^2_{D_s^+} - m^2_{K^{(*)0}})$ using the *Mathematica* and shown in the Fig. 16.1 as a function of square of momentum transfer.

The semileptonic differential branching are computed using (16.6) and presented in Fig. 16.2. The branching fractions are computed by integrating the differential branching fractions numerically. We obtain the following results:

$$\mathcal{B}(D_s^+ \to K^0e^+\nu_e) = 0.21\%, \quad \mathcal{B}(D_s^+ \to K^0\mu^+\nu_\mu) = 0.20\%,$$
$$\mathcal{B}(D_s^+ \to K^*(892)^0e^+\nu_e) = 0.19\%, \quad \mathcal{B}(D_s^+ \to K^*(892)^0\mu^+\nu_\mu) = 0.18\%$$

The experimental results are only available for the electron channel from the CLEO-c data [5]. Our results are in accordance with the CLEO-c data and also match with the results from LFQM data [6]. We also obtain the ratio $\Gamma(D_s^+ \to K^0\mu^+\nu_\mu)/\Gamma(D_s^+ \to K^0e^+\nu_e) = 0.98$ confirming the isospin symmetry of the kaons. The deviation from

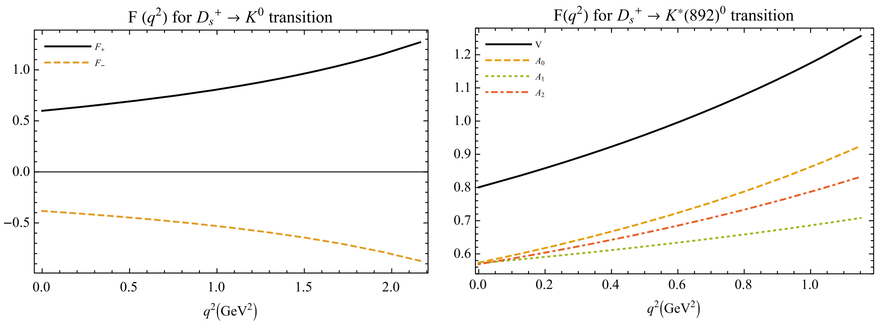

Fig. 16.1 Form factors

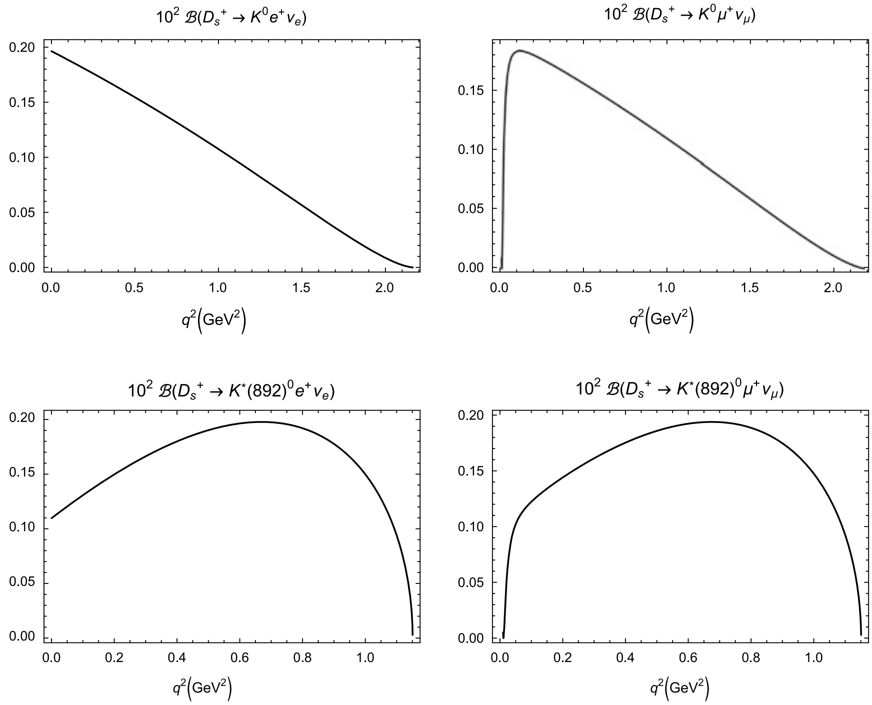

Fig. 16.2 Branching fractions

the Standard Model might be due to inherent uncertainties in the numerical computations. The muonic channels are yet to be confirmed from the experiments.

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