Eur. Phys. J. C (2026) 86:65
https://doi.org/10.1140/epjc/s10052-026-15301-2

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Theoretical Physics

Semileptonic $\Lambda_c \to \Lambda \ell \nu_\ell$ decays in light-cone QCD sum rules with Λ_c distribution amplitudes

T. M. Aliev[1,a], **S. Bilmis**[1,2,b], **M. Savci**[1,c]

[1] Department of Physics, Middle East Technical University, 06800 Ankara, Turkey
[2] TUBITAK ULAKBIM, 06510 Ankara, Turkey

Received: 3 November 2025 / Accepted: 4 January 2026
© The Author(s) 2026

Abstract We study the semileptonic decay of its SU(3) partner, the $\Lambda_c \to \Lambda \ell^+ \nu_\ell$ ($\ell = e, \mu$) transition, within the framework of light-cone QCD sum rules (LCSR) by using the distribution amplitudes of heavy Λ_c baryon. The numerical analysis is performed using two different sets of Λ_c baryon light-cone distribution amplitudes. The resulting form factors are parametrized by a model-independent z-series expansion and used to compute the differential and total decay widths. Our predictions for the branching fractions are in good agreement with the latest BESIII measurements and with lattice-QCD results.

1 Introduction

Heavy-flavor baryons provide an important testing ground for our understanding of the interplay between perturbative and nonperturbative aspects of quantum chromodynamics (QCD). In particular, semileptonic decays of charmed baryons serve as clean probes of the Standard Model (SM), as the leptonic current factorizes and hadronic uncertainties are confined to a limited set of form factors. Among them, the Λ_c baryon occupies a special role as the lightest charmed baryon with a relatively long lifetime and well-measured properties. Λ_c^+, undergoes the Cabibbo-favored transition $c \to s\, \ell^+ \nu_\ell$ predominantly through the channel $\Lambda_c \to \Lambda \ell \nu_\ell$ ($\ell = e, \mu$). Precise determinations of this decay rate depend on the Cabibbo–Kobayashi–Maskawa (CKM) matrix element $|V_{cs}|$ and on hadronic form factors, providing a stringent internal consistency test of the SM and offering sensitivity to potential new physics contributions.

Significant experimental progress has been achieved in the Λ_c sector in recent years [1]. Earlier theoretical estimates of the branching fraction $B(\Lambda_c^+ \to \Lambda e^+ \nu_e)$ spanned a wide range, from about 1.4 to 9.2% [2–14]. The BESIII Collaboration provided the first absolute measurement of the electronic mode in 2015, reporting $B(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (3.63 \pm 0.38 \pm 0.20)\%$ [15]. This was soon followed by the first absolute measurement of the muonic channel, $B(\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu) = (3.49 \pm 0.46 \pm 0.27)\%$ [16]. Benefiting from increased luminosity, BESIII subsequently provided the most precise measurement to date for the electronic branching fraction: $B(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (3.56 \pm 0.11 \pm 0.07)\%$ [17]. Notably, recent experiments have progressed beyond determining only the total branching fraction and have begun probing the underlying hadronic dynamics by providing the first direct comparisons of the differential decay rate and form factors with theoretical predictions. A combined analysis of the e and μ channels has further improved the precision of the form factor extraction and enabled the first test of lepton flavor universality in $\Lambda_c \to \Lambda \ell \nu_\ell$ decays [18].

On the theoretical side, the same decay has been studied using various theoretical approaches, including first-principles calculations using Lattice QCD (LQCD) [3,4,19] various quark models (constituent, relativistic, and light-front) [6,7,10–12], Heavy Quark Effective Theory (HQET) [2], and QCD sum rules (QCDSR) [9].While these methods have provided valuable insight, they often yield mutually inconsistent predictions for the form factors, and their uncertainties are not always fully quantified. In this context, new theoretical studies are essential.

A recent lattice QCD study [20] reported a discrepancy between theoretical predictions and experimental measurements in the semileptonic $\Xi_c \to \Xi \ell \nu_\ell$ decays. Motivated by this tension, in our previous work, we have investigated this decay channel using the light-cone sum rules (LCSR)

[a] e-mail: taliev@metu.edu.tr
[b] e-mail: sbilmis@metu.edu.tr (corresponding author)
[c] e-mail: savci@metu.edu.tr

Published online: 24 January 2026

approach with the distribution amplitudes of the initial Ξ_c baryon [21], and our results showed good agreement with the lattice predictions. This naturally raises the question of whether a similar situation could occur in the semileptonic decays of the Λ_c baryon, the SU(3) partner of the Ξ_c. The present work is devoted to addressing this question.

To compute the necessary form factors, we employ the light-cone sum rules method. The LCSR technique systematically incorporates nonperturbative effects through an expansion in terms of twist, replacing the short-distance operator product expansion (OPE) with a light-cone expansion. The reliability of LCSR predictions depends critically on the accuracy of the input distribution amplitudes.

In this study, we analyse the $\Lambda_c \to \Lambda \ell \nu_\ell$ decay within the LCSR framework by employing Λ_c-baryon light-cone distribution amplitudes (LCDAs) [22,23]. Our approach is based on the distribution amplitudes of the initial heavy baryon, Λ_c, although in principle analogous sum rules can also be formulated using the LCDAs of the final-state light baryon, Λ [9].

The paper is organized as follows. In Sect. 2, we present the theoretical framework and derive the sum rules for the relevant form factors describing the $\Lambda_c \to \Lambda$ transition. Section 3 contains the numerical analysis of these form factors, where we also provide results for the branching ratios and compare our findings with those reported in the literature. Finally, Sect. 4 summarizes our conclusions and outlines possible directions for future work.

2 Light-cone sum rules for the $\Lambda_c \to \Lambda$ transition

The effective Hamiltonian responsible for the semileptonic weak decay of the anti-triplet charmed baryon Λ_c is given by

$$\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}} V_{cs}\, \bar{s}\gamma^\mu(1-\gamma_5)c\; \bar{\nu}\gamma_\mu(1-\gamma_5)\ell, \tag{1}$$

where G_F is the Fermi coupling constant and V_{cs} denotes the CKM matrix element. The weak transition amplitude is obtained by inserting $\mathcal{H}_{eff}$ between the initial and final baryon states:

$$\begin{aligned} &M(\Lambda_c \to \Lambda \ell \nu_\ell) \\ &= \frac{G_F}{\sqrt{2}} V_{cs}\, \bar{\nu}\gamma^\mu(1-\gamma_5)\ell\, \langle \Lambda(p',s')|\bar{s}\gamma_\mu \\ &(1-\gamma_5)c|\Lambda_c(p,s)\rangle. \end{aligned} \tag{2}$$

The hadronic matrix element is parameterized in terms of six independent form factors as

$$\begin{aligned} &\langle \Lambda(p',s')|\bar{s}\gamma_\mu(1-\gamma_5)c|\Lambda_c(p,s)\rangle \\ &= \bar{u}_\Lambda(p',s')\Big[\gamma_\mu f_1(q^2) - i\sigma_{\mu\nu}\frac{q^\nu}{m_{\Lambda_c}} f_2(q^2) + \frac{q_\mu}{m_{\Lambda_c}} f_3(q^2) \\ &-\gamma_\mu\gamma_5 g_1(q^2) + i\sigma_{\mu\nu}\gamma_5\frac{q^\nu}{m_{\Lambda_c}} g_2(q^2) - \frac{q_\mu}{m_{\Lambda_c}} g_3(q^2)\gamma_5\Big] \\ &u_{\Lambda_c}(p,s), \end{aligned} \tag{3}$$

where $q = p - p'$ is the momentum transfer, m_{Λ_c} is the mass of the Λ_c baryon, and $f_i(q^2)$ and $g_i(q^2)$ $(i = 1, 2, 3)$ denote the vector and axial-vector form factors, respectively.

For the calculation of decay widths, it is convenient to introduce helicity amplitudes, which can be expressed directly in terms of the form factors. To express the helicity amplitudes $H^{V(A)}_{\lambda,\lambda_W}$ in terms of the form factors $f_i(q^2)$ and $g_i(q^2)$, we define $\lambda = \pm\frac{1}{2}$ as the helicity of the final-state Λ baryon and $\lambda_W = t, \pm 1, 0$ as the helicities of the virtual W boson. These amplitudes are obtained from

$$H_{\lambda,\lambda_W} = \langle \Lambda(p',\lambda)|\bar{s}\gamma_\mu(1-\gamma_5)c|\Lambda_c(p,\lambda)\rangle\, \varepsilon^{*\mu}(\lambda_W). \tag{4}$$

Following standard procedures (see, e.g., [6,21]), we obtain the explicit expressions:

$$\begin{aligned} H^V_{+1/2,t} &= \sqrt{\frac{Q_+}{q^2}}\left[m_- f_1 + \frac{q^2}{m_{\Lambda_c}} f_3\right], \\ H^V_{+1/2,+1} &= \sqrt{2Q_-}\left[f_1 + \frac{m_+}{m_{\Lambda_c}} f_2\right], \\ H^V_{+1/2,0} &= \sqrt{\frac{Q_-}{q^2}}\left[m_+ f_1 + \frac{q^2}{m_{\Lambda_c}} f_2\right], \\ H^A_{+1/2,t} &= \sqrt{\frac{Q_-}{q^2}}\left[g_1 m_+ - \frac{q^2}{m_{\Lambda_c}} g_3\right], \\ H^A_{+1/2,+1} &= \sqrt{2Q_+}\left[g_1 - \frac{m_-}{m_{\Lambda_c}} g_2\right], \\ H^A_{+1/2,0} &= \sqrt{\frac{Q_+}{q^2}}\left[g_1 m_- - \frac{q^2}{m_{\Lambda_c}} g_2\right], \end{aligned} \tag{5}$$

where

$$\begin{aligned} m_\pm &= m_{\Lambda_c} \pm m_\Lambda, \\ Q_\pm &= m_\pm^2 - q^2, \end{aligned}$$

and m_{Λ_c} and m_Λ are the masses of the Λ_c and Λ baryons, respectively.

The helicity amplitudes satisfy the following symmetry relations,

$$\begin{aligned} H^V_{-\lambda,-\lambda_W} &= -H^V_{\lambda,\lambda_W}, \\ H^A_{-\lambda,-\lambda_W} &= +H^A_{\lambda,\lambda_W}. \end{aligned}$$

Using these helicity amplitudes, the differential decay width can be obtained as

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2|V_{cs}|^2}{192\pi^3}\frac{(q^2-m_\ell^2)^2|\vec{p}|}{m_{\Lambda_c}^2 q^2} H_{tot}, \tag{6}$$

where

$$H_{tot} = \left(1+\frac{m_\ell^2}{2q^2}\right)\Big[|H_{+1/2,+1}|^2+|H_{-1/2,-1}|^2 +|H_{+1/2,0}|^2+|H_{-1/2,0}|^2\Big] +\frac{3m_\ell^2}{2q^2}\Big[|H_{+1/2,t}|^2+|H_{-1/2,t}|^2\Big]. \quad (7)$$

The magnitude of the three-momentum of the final-state baryon is

$$|\vec{p}| = \frac{1}{2m_{\Lambda_c}}\lambda^{1/2}(m_{\Lambda_c}^2, m_\Lambda^2, q^2),$$

where the Källén function λ is defined as

$$\lambda(a,b,c) = a^2+b^2+c^2-2ab-2ac-2bc.$$

In Eq. (7) H_{λ,λ_w} is defined as

$$H_{\lambda,\lambda_W} = H^V_{\lambda,\lambda_W} - H^A_{\lambda,\lambda_W}. \quad (8)$$

To determine the form factors responsible for the $\Lambda_c \to \Lambda$ transition, we use the light-cone QCD sum rule method. Within this framework, we start from the correlation function

$$\Pi_\mu = i\int d^4x\, e^{ip'x}\langle 0|\eta_\Lambda(x)\,\bar{J}_\mu(0)|\Lambda_c(p)\rangle,$$

where $\eta_\Lambda(x)$ is the interpolating current for the Λ baryon, defined as

$$\eta_\Lambda(x) = \frac{2}{\sqrt{6}}\epsilon^{abc}\sum_{\ell=1}^{2}\Big\{2\big[u^a(x)A^\ell d^b(x)\big]B^\ell s^c(x) +\big[u^a(x)A^\ell s^b(x)\big]B^\ell d^c(x) +\big[s^a(x)A^\ell d^b(x)\big]B^\ell u^c(x)\Big\},$$

and $\bar{J}_\mu = \bar{s}\gamma_\mu(1-\gamma_5)c$ denoting the weak transition current. Here a,b,c are color indices, $A^1=\mathbb{I}$, $A^2=C\gamma_5$, $B^1=\gamma_5$, $B^2=\beta\mathbb{I}$, and C is the charge conjugation operator. The interpolating current η_Λ is constructed to match the quantum numbers of the Λ baryon and is used in the evaluation of the QCD side of the correlation function.

Taking into account the Dirac equation $(\not{p}-m)u(p)=0$, the correlation function can be expressed in terms of independent invariant amplitudes. For the vector and axial-vector currents, six invariant amplitudes arise in each case. The full decomposition of the correlation function reads

$$\Pi_\mu = \big[\Pi_1\, v_\mu \not{q} + \Pi_2\,\gamma_\mu\not{q} + \Pi_3\, q_\mu + \Pi_4 v_\mu +\Pi_5\gamma_\mu + \Pi_6\, q_\mu\not{q}\big]u(v) -\big[\Pi_7\, v_\mu\not{q} + \Pi_8\,\gamma_\mu\not{q} + \Pi_9\, q_\mu + \Pi_{10}v_\mu +\Pi_{11}\gamma_\mu + \Pi_{12}\, q_\mu\not{q}\big]\gamma_5\, u(v), \quad (9)$$

where we introduced $p_\mu = m_{\Lambda_c}v_\mu$ and used the heavy-baryon velocity notation,

$$|\Lambda_c(p)\rangle = \sqrt{m_{\Lambda_c}}\,|\Lambda_c(v)\rangle.$$

Using the definition $\langle 0|\eta_\Lambda|\Lambda(p')\rangle = \lambda\, u(p')$, together with the decomposition of the $\Lambda_c \to \Lambda$ transition form factors and after performing the spin summation over the Λ baryon, one obtains the hadronic representation of the correlation function in terms of invariant amplitudes.

$$\begin{aligned}\Pi_\mu(p,q) = \frac{\lambda}{m_\Lambda^2-p'^2}\Big\{& f_1\Big[2m_{\Lambda_c}v_\mu + (m_\Lambda - m_{\Lambda_c})\gamma_\mu -2q_\mu + \gamma_\mu\not{q}\Big] \\ &+\frac{f_2}{m_{\Lambda_c}}\Big[2m_{\Lambda_c}v_\mu\not{q} + (m_\Lambda^2 - m_{\Lambda_c}^2)\gamma_\mu + (m_\Lambda \\ &+m_{\Lambda_c})\gamma_\mu\not{q} - q_\mu(m_\Lambda + m_{\Lambda_c}) - q_\mu\not{q}\Big] \\ &+\frac{f_3}{m_{\Lambda_c}}\, q_\mu(m_\Lambda + m_{\Lambda_c} - \not{q}) \\ &-g_1\Big[2m_{\Lambda_c}v_\mu + (m_\Lambda + m_{\Lambda_c})\gamma_\mu - 2q_\mu + \gamma_\mu\not{q}\Big]\gamma_5 \\ &-\frac{g_2}{m_{\Lambda_c}}\Big[2m_{\Lambda_c}v_\mu\not{q} + (m_\Lambda^2 - m_{\Lambda_c}^2)\gamma_\mu \\ &+(m_\Lambda - m_{\Lambda_c})\gamma_\mu\not{q} - q_\mu(m_\Lambda - m_{\Lambda_c}) - q_\mu\not{q}\Big]\gamma_5 \\ &-\frac{g_3}{m_{\Lambda_c}}\, q_\mu(m_\Lambda - m_{\Lambda_c} - \not{q})\gamma_5\Big\}u(v). \end{aligned} \quad (10)$$

This hadronic representation will subsequently be matched to the QCD calculation in the next step.

We now turn our attention to the calculation of the correlation function from QCD side. The external four-momenta are taken space-like, $p'^2, q^2 \ll m_c^2$, so that the correlation function can be expanded near the light cone ($x^2 \simeq 0$). In this regime, the operator product expansion (OPE) is obtained in terms of the light-cone distribution amplitudes of the Λ_c baryon, ordered by twist, convoluted with the hard-scattering amplitudes involving the virtual s-quark propagator.

After applying Wick's theorem, the correlation function takes the form

$$\begin{aligned}(\Pi_\mu)_\rho =& \frac{2}{\sqrt{6}}\epsilon^{abc}\sum_{\ell=1}^{2}\int d^4x\, e^{ip'x}(A^\ell)_{\alpha\beta}(B^\ell)_{\rho\gamma}(\gamma_\mu(1-\gamma_5))_{h\eta} \\ &\times\Big\{2S_{\gamma h}\langle 0|u_\alpha^a(x)d_\beta^b(x)c_\eta^c(0)|\Lambda_c\rangle \\ &+S_{\beta h}\langle 0|u_\alpha^a(x)d_\gamma^b(x)c_\eta^c(0)|\Lambda_c\rangle \\ &+S_{\alpha h}\langle 0|u_\gamma^a(x)d_\beta^b(x)c_\eta^c(0)|\Lambda_c\rangle\Big\}, \end{aligned} \quad (11)$$

where S denotes the s-quark propagator.

The matrix element

$$\langle 0|u_\alpha^a(x)\, d_\beta^b(x)\, c_\gamma^c(0)|\Lambda_c(v)\rangle,$$

is parameterized in terms of the light-cone distribution amplitudes of the Λ_c baryon [22]. It can be written as

$$\epsilon^{abc}\langle 0|u^a_\alpha(t_1 n)\, d^b_\beta(t_2 n)\, h^c_\gamma(0)|\Lambda_c(v)\rangle = \sum_{i=1}^{4}\alpha_i\,[\Gamma_i]_{\beta\alpha}\,(u_i(v))_\gamma, \tag{12}$$

where h_c^γ is the heavy-quark field in HQET, Γ_i denote the relevant Dirac structures, $u_\gamma(v)$ is the heavy baryon spinor, α_i' are coefficient functions defined below, and ψ_i are the light-cone DAs of the Λ_c baryon.

The explicit expressions of the coefficients are

$$\begin{aligned}
\alpha_1 &= \tfrac{1}{8} f^{(2)}\,\psi_2(t_1,t_2),\\
\alpha_2 &= \tfrac{1}{8} f^{(1)}\,\psi_3^\sigma(t_1,t_2),\\
\alpha_3 &= \tfrac{1}{4} f^{(1)}\,\psi_3^s(t_1,t_2),\\
\alpha_4 &= \tfrac{1}{8} f^{(2)}\,\psi_4(t_1,t_2),
\end{aligned} \tag{13}$$

with the corresponding Dirac structures

$$\begin{aligned}
\Gamma_1 &= \not{n}\gamma_5 C^{-1},\\
\Gamma_2 &= i\sigma_{\mu\nu}\bar{n}^\mu n^\nu \gamma_5 C^{-1},\\
\Gamma_3 &= \gamma_5 C^{-1},\\
\Gamma_4 &= \not{\bar{n}}\gamma_5 C^{-1}.
\end{aligned} \tag{14}$$

Here, the subscript i in ψ_i indicates the twist of the DA. The light-cone vectors are defined as

$$n_\mu = \frac{x_\mu}{vx}, \quad \bar{n}_\mu = 2v_\mu - n_\mu.$$

The distribution amplitudes $\psi(t_1,t_2)$ in coordinate space are related to their momentum-space representation $\psi(u,\omega)$ through the Fourier transform

$$\psi(t_1,t_2) = \int_0^1 du \int_0^\infty d\omega\,\omega\, e^{-i\omega(t_1\bar{u}+t_2 u)}\,\psi(u,\omega),$$

where ω denotes the total momentum carried by the two light quarks and $\bar{u} = 1-u$. In the special case $t_1 = t_2 = vx$, this simplifies to

$$\psi(t_1,t_2) = \int_0^1 du \int_0^\infty d\omega\,\omega\, e^{-i\omega vx}\,\psi(u,\omega).$$

Using these definitions, the QCD representation of the correlation function can be written as

$$\begin{aligned}
(\Pi_\mu^{\rm QCD})_\rho = \frac{2}{\sqrt{6}}\, i\int d^4x \int_0^1 du\int_0^\infty d\omega\,\omega\, e^{i(p'-\omega v)x}\\
\sum_{\ell=1}^{2}\sum_{i=1}^{4}\alpha_i (A^\ell)_{\alpha\beta}(B^\ell)_{\rho\gamma}(\gamma_\mu(1-\gamma_5))_{h\eta}\\
\times\Big\{2(\Gamma_i)_{\beta\alpha}S_{\gamma h}(x) - (\Gamma_i)_{\gamma\alpha}S_{\beta h}(x) + (\Gamma_i)_{\alpha\gamma}S_{\beta h}(x)\Big\}\\
u_\eta(v).
\end{aligned} \tag{15}$$

After performing the Fourier transformation of the propagator and integrating over x, the final expression for the QCD side of the correlation function becomes

$$\begin{aligned}
\Pi_\mu^{\rm QCD} = \frac{2}{\sqrt{6}}\int_0^1 du\int_0^\infty \omega\, d\omega \sum_{\ell=1}^{2}\sum_{i=1}^{4}\alpha_i\\
\times\Big\{2\,{\rm Tr}[\Gamma_i A^\ell]\, B^\ell\,\frac{\not{p}' - \omega\not{v} + m_s}{m_s^2-(p'-\omega v)^2}\,\gamma_\mu(1-\gamma_5)\\
+B^\ell\Gamma_i A^\ell\,\frac{\not{p}' - \omega\not{v} + m_s}{m_s^2-(p'-\omega v)^2}\,\gamma_\mu(1-\gamma_5)\\
+B^\ell\,\Gamma_i^T A^{\ell T}\,\frac{\not{p}' - \omega\not{v} + m_s}{m_s^2-(p'-\omega v)^2}\,\gamma_\mu(1-\gamma_5)\Big\}u(v).
\end{aligned} \tag{16}$$

The final step in obtaining the sum rules for the $\Lambda_c \to \Lambda$ transition form factors is to identify the same Lorentz structures from both the hadronic and QCD representations of the correlation function and match their coefficients.

By isolating the structures proportional to $\not{q}v_\mu$, $\gamma_\mu\not{q}$, q_μ, $\not{q}\gamma_5 v_\mu$, $\gamma_\mu\not{q}\gamma_5$, and $\gamma_5 q_\mu$, we arrive at the following sum rules for the form factors, respectively:

$$\begin{aligned}
&\frac{2\lambda_\Lambda}{m_\Lambda^2-p'^2}f_2 = \Pi_1,\\
&\frac{\lambda_\Lambda}{m_\Lambda^2-p'^2}\left[f_1 + \frac{m_\Lambda+m_{\Lambda_c}}{m_{\Lambda_c}}f_2\right] = \Pi_2,\\
&-\frac{\lambda_\Lambda}{m_\Lambda^2-p'^2}\left[2f_1 + \frac{m_\Lambda+m_{\Lambda_c}}{m_{\Lambda_c}}f_2 - \frac{m_\Lambda+m_{\Lambda_c}}{m_{\Lambda_c}}f_3\right] = \Pi_3,\\
&-\frac{2\lambda_\Lambda}{m_\Lambda^2-p'^2}g_2 = \Pi_4,\\
&-\frac{\lambda_\Lambda}{m_\Lambda^2-p'^2}\left[g_1 + \frac{m_\Lambda-m_{\Lambda_c}}{m_{\Lambda_c}}g_2\right] = \Pi_5,\\
&\frac{\lambda_\Lambda}{m_\Lambda^2-p'^2}\left[2g_1 + \frac{m_\Lambda-m_{\Lambda_c}}{m_{\Lambda_c}}g_2 - \frac{m_\Lambda-m_{\Lambda_c}}{m_{\Lambda_c}}g_3\right] = \Pi_6.
\end{aligned} \tag{17}$$

The invariant functions Π_i can, in general, be represented as

$$\Pi_i = \int_0^1 du\int \sigma\, d\sigma\left[\frac{\rho_i^{(1)}(\sigma)}{\bar{\sigma}\,\Delta} + \frac{\rho_i^{(2)}(\sigma)}{\bar{\sigma}^2\Delta^2} + \frac{\rho_i^{(3)}(\sigma)}{\bar{\sigma}^3\Delta^3}\right], \tag{18}$$

where

$$\begin{aligned}
\Delta &= p'^2 - s(\omega),\\
s(\omega) &= \frac{m_s^2 + m_{\Lambda_c}^2\bar{\sigma} - \sigma q^2}{\bar{\sigma}},\\
\sigma &= \frac{\omega}{m_{\Lambda_c}}, \qquad \bar{\sigma} = 1-\sigma.
\end{aligned}$$

Explicit expressions for the spectral densities $\rho_i^{(j)}$ are lengthy and are therefore omitted here. To suppress contributions from higher states and the continuum, we invoke quark-hadron duality in the Λ channel, replacing the hadronic spectral density with the integral of the OPE spectral density

above an effective threshold s_0. Applying a Borel transformation in p'^2, the resulting relation is

$$\int_0^{s_0} ds\,\frac{I_n}{(p'^2-s)^n} = \int_0^{\sigma_0} d\sigma\,(-1)^n \frac{e^{-s(\sigma)/M^2} I_n}{(n-1)!(M^2)^{n-1}} + \left[\frac{(-1)^n}{(n-1)!} e^{-s/M^2} \sum_{j=1}^{n-1} \frac{1}{(M^2)^{n-j-1}} \frac{1}{s'} \left(\frac{d}{d\sigma}\frac{1}{s'}\right)^{j-1} I_n\right]_{\sigma=\sigma_0},$$

where M is the Borel parameter, and

$$s' = \frac{ds}{d\sigma},$$
$$I_n(\sigma) = \frac{\sigma \rho_n}{\bar{\sigma}},$$
$$\left(\frac{d}{d\sigma}\frac{1}{s'}\right)^{j-1} I_n(\sigma) \Rightarrow \left[\frac{d}{d\sigma}\frac{1}{s'}\left(\frac{d}{d\sigma}\frac{1}{s'}\cdots\right)\right] I_n(\sigma),$$
$$\sigma_0 = \frac{s + m_\Lambda^2 - q^2 - \sqrt{4(m_s^2 - s_0)m_\Lambda^2 + (m_\Lambda^2 + s_0 - q^2)^2}}{2m_\Lambda^2}.$$

As a result, the sum rules for the form factors can be expressed in the compact form

$$F_i^{\text{form factor}} = \frac{1}{K_i} e^{m_p \Lambda^2/M^2} \sum_{n=1}^{\infty} \mathcal{B}_i^{(n)},$$

where $F_i \in \{f_i, g_i\}$ denote the form factors, K_i are kinematic factors containing residues, masses, and normalization constants, $i = 1, \ldots, 6$ labels the corresponding form factor, and $\mathcal{B}_i^{(n)}$ represents the Borel-transformed and subtracted invariant amplitude.

3 Numerical analysis

In this section, we present the numerical analysis of the sum rules for the $\Lambda_c \to \Lambda$ transition form factors. As discussed earlier, the main nonperturbative inputs of the light-cone sum rules are the distribution amplitudes.

In this work, we adapt two different sets of light-cone distribution amplitudes (LCDAs) of the Λ_b baryon obtained in [22,23] and apply the same functional forms to the Λ_c by replacing the heavy-quark parameters accordingly. This approach assumes that the shape of the heavy-baryon LCDAs is largely insensitive to the heavy-quark flavor, while possible $1/m_c$ corrections are neglected. The explicit expressions of first set of DAs (named as DAs-set I) obtained in [22]

$$\psi_2(\omega,u) = \frac{15}{2} A^{-1} \omega^2 \bar{u} u \int_{\omega/2}^{s_0} ds\, e^{-s/y}(s-\omega/2),$$
$$\psi_4(\omega,u) = 5A^{-1} \int_{\omega/2}^{s_0} ds\, e^{-s/y}(s-\omega/2)^3,$$
$$\psi_{3s}(\omega,u) = \frac{15}{4} A^{-1} \omega \int_{\omega/2}^{s_0} ds\, e^{-s/y}(s-\omega/2)^2,$$
$$\psi_{3\sigma}(\omega,u) = \frac{15}{4} A^{-1} \omega(2u-1) \int_{\omega/2}^{s_0} ds\, e^{-s/y}(s-\omega/2)^2,$$

Table 1 Input parameters used in the analysis

Parameter	Value
$m_c(\overline{m_c})$	1.273 ± 0.046 GeV [24]
$m_s(2\,\text{GeV})$	93.5 ± 0.8 MeV [24]
$f^{(1)} = f^{(2)}$	$(2.3 \pm 0.2) \times 10^{-2}$ GeV^3 [25]
m_{Λ_c}	2.286 GeV [24]
m_Λ	1.115 GeV [24]

(19)

where

$$A = \int_0^{s_0} ds\, s^5 e^{-s/y}.$$

Here, y and s_0 denote the Borel parameter and the continuum threshold, respectively [22]. From the QCD sum-rule analysis, y is found to vary in the range $0.4\,\text{GeV} < y < 0.8\,\text{GeV}$, while the continuum threshold is fixed at $s_0 = 1.2$ GeV.

The second set of Λ_c DAs (named ad DAs-set II) was obtained in Ref. [23] and takes the form

$$\psi_2(u,\omega) = \omega^2 u\bar{u} \sum_{i=0}^{2} \frac{a_i}{\varepsilon_i^4} \frac{C_i^{3/2}(2u-1)}{|C_i^{3/2}|^2} e^{-\omega/\varepsilon_i},$$
$$\psi_3^{(\sigma,s)}(u,\omega) = \frac{\omega}{2} \sum_{i=0}^{2} \frac{a_i}{\varepsilon_i^2} \frac{C_i^{1/2}(2u-1)}{|C_i^{3/2}|^2} e^{-\omega/\varepsilon_i},$$
$$\psi_4(u,\omega) = \sum_{i=0}^{2} \frac{a_i}{\varepsilon_i^2} \frac{C_i^{1/2}(2u-1)}{|C_i^{1/2}|^2} e^{-\omega/\varepsilon_i}, \tag{20}$$

where $C_i^\ell(2u-1)$ are Gegenbauer polynomials, and the normalization factor is defined as

$$|C_i^\ell|^2 = \int_0^1 du \left[C_i^\ell(2u-1)\right]^2.$$

The values of the parameters a_i and ε_i are taken from Ref. [23] with the parameter A fixed to 0.5.

The numerical values of the input parameters entering the sum rules are listed in Table 1.

The sum rules involve three auxiliary parameters: the Borel mass M^2, the continuum threshold s_0, and the mixing parameter β (here we take $\beta = -1$, i.e., Ioffe current) that appears in the interpolating current. Physical observables should not depend on these parameters, so our first task is to determine their working regions.

The continuum threshold s_0 is determined following the standard QCD sum-rule procedure: we consider the ratio of the derivative of the two-point sum rule with respect to $-1/M^2$ to the sum rule itself, and require that this ratio reproduces the baryon mass within about 10% accuracy. This criterion ensures a consistent and theoretically motivated determination of s_0.

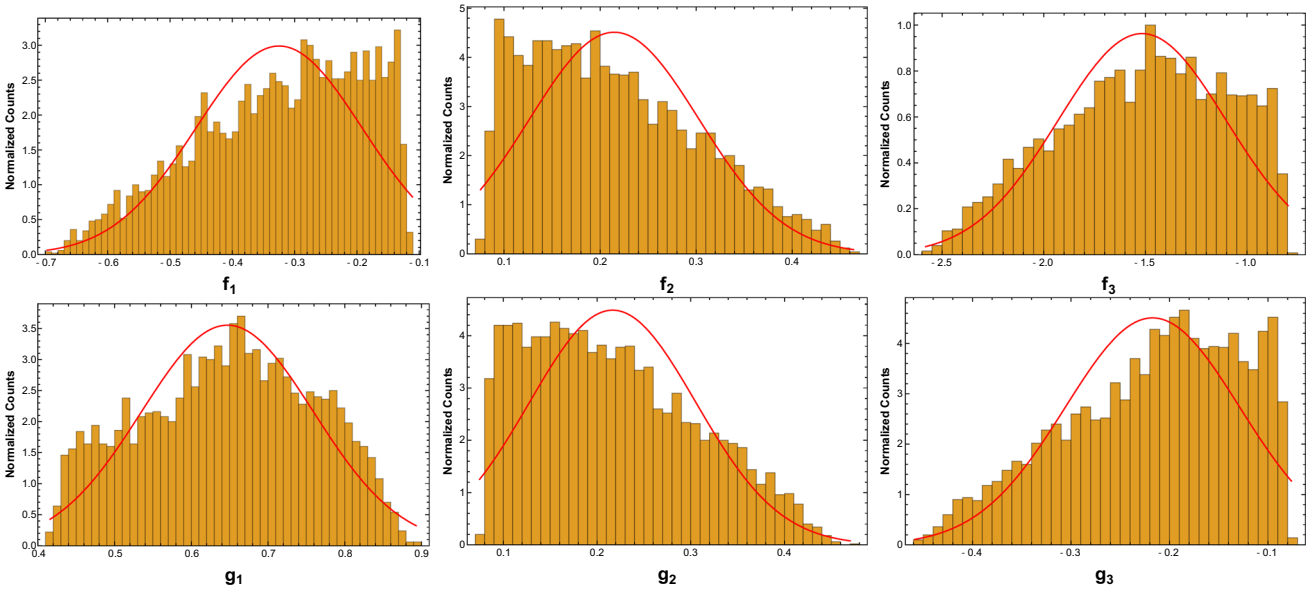


Fig. 1 Normalized distributions of the $\Lambda_c^+ \to \Lambda^0 \ell^+ \nu$ form factors f_i and g_i at $q^2 = 0$ obtained from LCSR. The solid lines represent Gaussian fits to the Monte Carlo distributions. For illustration, only the results corresponding to the DAs-set-I are shown

The working region of the Borel mass parameter M^2 is fixed by the usual requirements of QCD sum rules. First, M^2 must be sufficiently large to suppress higher-twist contributions and ensure the reliability of the operator product expansion. Second, M^2 should not be taken too large, so as to preserve the dominance of the ground-state contribution and suppress the effects of higher resonances and the continuum.

Our numerical analysis shows that these conditions are simultaneously satisfied within the following windows:

$$2.0\,\text{GeV}^2 \le s_0 \le 4.0\,\text{GeV}^2, \quad 1.0\,\text{GeV}^2 \le M^2 \le 3.0\,\text{GeV}^2.$$

Within these working regions, the form factors show only a weak sensitivity to the auxiliary parameters and exhibit good stability with respect to their variation.

Having obtained the working regions of auxiliary parameters s_0 and M^2, we next investigate the q^2-dependence of the form factors. The physical range of momentum transfer for the semileptonic decay $\Lambda_c \to \Lambda \ell \nu$ is

$$m_\ell^2 < q^2 < (m_{\Lambda_c} - m_\Lambda)^2,$$

but the LCSR predictions are most reliable near $q^2 \simeq 0$, and more precisely in the region $q^2 \lesssim 0.5$ GeV^2. To extend the form factors across the entire physical region, we adopt the z-series expansion [26],

$$f(q^2) = \frac{1}{1 - q^2/m_{\text{pole}}^2} \left\{ a_0^f + a_1^f\, z(q^2) + a_2^f\, z^2(q^2) \right\},$$

where the conformal variable z is defined as

$$z(q^2) = \frac{\sqrt{t_+ - q^2} - \sqrt{t_+ - t_0}}{\sqrt{t_+ - q^2} + \sqrt{t_+ - t_0}},$$

with $t_+ = (m_{\Lambda_c} + m_\Lambda)^2$. Here m_{pole} corresponds to the lowest-lying resonance with the same quantum numbers as the current mediating the transition:

$$m_{\text{pole}} = \begin{cases} 2.010\ \text{GeV} & \text{for } f_1,\, f_2, \\ 2.413\ \text{GeV} & \text{for } g_1,\, g_2, \\ 2.300\ \text{GeV} & \text{for } f_3, \\ 1.870\ \text{GeV} & \text{for } g_3. \end{cases}$$

The fitting parameters a_0^f, a_1^f, and a_2^f for each form factor are determined by matching the z-series parametrization to the LCSR predictions in the region $q^2 < 0.5$ GeV^2. To simultaneously account for uncertainties in the input parameters and form factors, we employ a Monte Carlo analysis. In particular, we generate 5000 samples by randomly varying the input parameters within their quoted uncertainties and compute the corresponding form factors at $q^2 = 0$. The resulting distributions are used to extract the central values and uncertainties of the form factors, which are summarized in Table 2. For illustration, only the results obtained using the DAs-set I are shown in Fig. 1.

Using the form factors listed in Table 2, we evaluate the decay widths and branching ratios of the semileptonic channels $\Lambda_c^+ \to \Lambda^0 e^+ \nu_e$ and $\Lambda_c^+ \to \Lambda^0 \mu^+ \nu_\mu$ using Eq. (6).

Table 2 Form factors for the $\Lambda_c \to \Lambda$ transition at $q^2 = 0$, obtained using two different sets of Λ_c DAs

Form factor	Set I [22]	Set II [23]
$f_1(0)$	-0.32 ± 0.13	-0.65 ± 0.08
$f_2(0)$	0.21 ± 0.09	0.44 ± 0.05
$f_3(0)$	-1.52 ± 0.41	-2.37 ± 0.20
$g_1(0)$	0.65 ± 0.11	0.79 ± 0.04
$g_2(0)$	0.22 ± 0.09	0.44 ± 0.05
$g_3(0)$	-0.22 ± 0.09	-0.44 ± 0.05

The branching fractions derived after the phase-space integrations are given in Table 3.

A comparison with the BESIII measurement indicates that the predictions are in good agreement with experiment. We stress that closer agreement of a central value with experiment does not imply an exact fit or establish the superiority of a given LCDA set. Within the quoted uncertainties both sets yield mutually compatible predictions.

As mentioned earlier, the $\Lambda_c \to \Lambda \ell \nu_\ell$ decays have been studied extensively within a variety of theoretical frameworks. For completeness, in Table 4 we summarize our branching ratio predictions together with those obtained from various theoretical approaches and experiments.

We observe from Table 4 that our predictions are consistent with most theoretical approaches and, in particular, agree well with the BESIII measurements within uncertainties, with the exception of the CQM [6] and LFQM [10] results. It is worth emphasizing that this decay has been investigated in the LCSR approach using the distribution amplitudes of the light Λ baryon in Ref. [9]. In the present work, we adopt the same LCSR strategy, but employ the light-cone distribution amplitudes of the initial heavy baryon Λ_c. Although these two frameworks employ different nonperturbative inputs and differ technically in the construction of the correlation functions, they yield compatible predictions for the form factors and branching ratios within uncertainties. This agreement indicates that the two formulations provide consistent descriptions of the $\Lambda_c \to \Lambda \ell \nu$ transition within the LCSR methodology.

Future refinements of this analysis could include the incorporation of $\mathcal{O}(\alpha_s)$ radiative corrections, the inclusion of subleading $1/m_c$ contributions, and a more precise determination of the nonperturbative input parameters that enter the DA definitions.

At the end of this section, we would like to note that we also performed analysis for the other set of Lorentz structures and found out that the results for the form factors vary slightly.

Table 3 Predicted branching fractions (%) for $\Lambda_c^+ \to \Lambda^0 \ell^+ \nu_\ell$ decays obtained using two different sets of Λ_c distribution amplitudes (DAs)

	$\mathcal{B}(\Lambda_c^+ \to \Lambda^0 e^+ \nu_e)$	$\mathcal{B}(\Lambda_c^+ \to \Lambda^0 \mu^+ \nu_\mu)$
Set I	$3.56 \pm 0.85\%$	3.51 ± 0.84
Set II	$3.90 \pm 0.94\%$	3.88 ± 0.93

Table 4 Branching fractions (%) for $\Lambda_c^+ \to \Lambda^0 \ell^+ \nu_\ell$ from various theoretical approaches and experiment

Model/experiment	$\mathcal{B}(\Lambda_c^+ \to \Lambda^0 e^+ \nu_e)$	$\mathcal{B}(\Lambda_c^+ \to \Lambda^0 \mu^+ \nu_\mu)$
LQCD [3]	3.88 ± 0.19	3.75 ± 0.19
LQCD [4]	3.80 ± 0.22	3.69 ± 0.22
HBM [5]	3.78 ± 0.25	3.67 ± 0.23
CQM [6]	2.78	2.69
RQM [7]	3.25	3.14
NRQM [8]	3.84	3.72
QCDSR [9]	3.49 ± 0.65	3.37 ± 0.54
LFQM [10]	1.63	–
LFQM [11]	3.55 ± 0.104	3.40 ± 0.102
LFQM [12]	4.04 ± 0.75	3.90 ± 0.73
$SU(3)_F$ [13,14]	3.6 ± 0.4	3.5 ± 0.4
ARGUS [27]	–	2.37 ± 0.51
CLEO [28]	–	2.68 ± 0.51
BESIII [16,17]	3.56 ± 0.13	3.48 ± 0.20
This work	3.56 ± 0.85 (set-I)	3.51 ± 0.84 (set-I)
	3.90 ± 0.94 (set-II)	3.88 ± 0.93 (set-II)

4 Conclusion

Motivated by the recent lattice-experiment tension observed in $\Xi_c \to \Xi \ell^+ \nu_\ell$ transitions, in this work we have investigated the semileptonic decay of the SU(3) partner baryon, $\Lambda_c \to \Lambda \ell^+ \nu_\ell$ ($\ell = e, \mu$), within the framework of light-cone QCD sum rules (LCSR). The sum rules are derived for all form factors, while the numerical analysis is performed using two different sets of Λ_c baryon light-cone distribution amplitudes (LCDAs). Using the obtained results for the form factors, we estimated the branching ratios of the corresponding decays. Our results are in good agreement with the latest BESIII measurements and with lattice-QCD predictions. It is worth noting that our results are also consistent with those obtained from QCD sum rules employing the Λ-baryon distribution amplitudes [9]. This agreement indicates that, in contrast to the Ξ_c case, both formulations based on heavy- or light-baryon DAs yield compatible predictions for the $\Lambda_c \to \Lambda$ transition. The absence of any noticeable deviation between theoretical and experimental results in this channel suggests that the discrepancy observed in the Ξ_c decays may not be universal and could arise from either theoretical or experimental sources specific to the Ξ_c sector.

Since the Λ_b LCDAs were employed as an approximation, subleading $1/m_c$ corrections and the eventual determination of genuine Λ_c distribution amplitudes are expected to further improve the precision of the predictions. Future extensions of this analysis may also include $\mathcal{O}(\alpha_s)$ radiative corrections, which would enhance the predictive power of the LCSR framework for charmed baryon decays. Such developments would reduce theoretical uncertainties and provide more robust predictions for comparison with forthcoming lattice and experimental results.

Funding No funding received for this article.

Data Availability Statement This manuscript has no associated data. [Authors' comment: This work is a theoretical study. All numerical results are obtained from analytical expressions using input parameters taken from the literature. No new datasets were generated or analysed during the current study.]

Code Availability Statement This manuscript has no associated code/software. [Authors' comment: No code or software was generated or analysed during the current study.]

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.
Funded by SCOAP[3].

References

1. P.-R. Li, X.-R. Lyu, Y. Zheng, Experimental overview on the charmed baryon decays. arXiv:2509.19141
2. H.-Y. Cheng, B. Tseng, 1/M corrections to baryonic form-factors in the quark model. Phys. Rev. D **53**, 1457 (1996). https://doi.org/10.1103/PhysRevD.53.1457. arXiv:hep-ph/9502391. [Erratum: Phys. Rev. D **55**, 1697 (1997)]
3. Z.-H. Zhang, Y. Li, Investigation of $\Lambda_c \to (\Lambda, n)\ell^+\nu_\ell$ decays in the standard model and beyond. Phys. Rev. D **111**(5), 053008 (2025). https://doi.org/10.1103/PhysRevD.111.053008. arXiv:2501.12871
4. S. Meinel, $\Lambda_c \to \Lambda l^+\nu_l$ form factors and decay rates from lattice QCD with physical quark masses. Phys. Rev. Lett. **118**(8), 082001 (2017). https://doi.org/10.1103/PhysRevLett.118.082001. arXiv:1611.09696
5. C.-Q. Geng, X.-N. Jin, C.-W. Liu, Anatomy of Λ_c^+ semileptonic decays. Phys. Rev. D **107**(3), 033008 (2023). https://doi.org/10.1103/PhysRevD.107.033008. arXiv:2210.15588
6. T. Gutsche, M.A. Ivanov, J.G. Korner, V.E. Lyubovitskij, P. Santorelli, Semileptonic decays $\Lambda_c^+ \to \Lambda\ell^+\nu_\ell$ ($\ell = e, \mu$) in the covariant quark model and comparison with the new absolute branching fraction measurements of Belle and BESIII. Phys. Rev. D **93**(3), 034008 (2016). https://doi.org/10.1103/PhysRevD.93.034008. arXiv:1512.02168
7. R.N. Faustov, V.O. Galkin, Semileptonic decays of Λ_c baryons in the relativistic quark model. Eur. Phys. J. C **76**(11), 628 (2016). https://doi.org/10.1140/epjc/s10052-016-4492-z. arXiv:1610.00957
8. M.M. Hussain, W. Roberts, Λ_c semileptonic decays in a quark model. Phys. Rev. D **95**(5), 053005 (2017). https://doi.org/10.1103/PhysRevD.95.053005. arXiv:1701.03876. [Addendum: Phys. Rev. D **95**, 099901 (2017)]
9. S.-Q. Zhang, C.-F. Qiao, Λ_c semileptonic decays. Phys. Rev. D **108**(7), 074017 (2023). https://doi.org/10.1103/PhysRevD.108.074017. arXiv:2307.05019
10. Z.-X. Zhao, Weak decays of heavy baryons in the light-front approach. Chin. Phys. C **42**(9), 093101 (2018). https://doi.org/10.1088/1674-1137/42/9/093101. arXiv:1803.02292
11. C.Q. Geng, C.-W. Liu, T.-H. Tsai, Semileptonic weak decays of antitriplet charmed baryons in the light-front formalism. Phys. Rev. D **103**(5), 054018 (2021). https://doi.org/10.1103/PhysRevD.103.054018. arXiv:2012.04147
12. Y.-S. Li, X. Liu, F.-S. Yu, Revisiting semileptonic decays of $\Lambda_{b(c)}$ supported by baryon spectroscopy. Phys. Rev. D **104**(1), 013005 (2021). https://doi.org/10.1103/PhysRevD.104.013005. arXiv:2104.04962
13. C.-Q. Geng, C.-W. Liu, T.-H. Tsai, S.-W. Yeh, Semileptonic decays of anti-triplet charmed baryons. Phys. Lett. B **792**, 214–218 (2019). https://doi.org/10.1016/j.physletb.2019.03.056. arXiv:1901.05610
14. X.-G. He, F. Huang, W. Wang, Z.-P. Xing, SU(3) symmetry and its breaking effects in semileptonic heavy baryon decays. Phys. Lett. B **823**, 136765 (2021). https://doi.org/10.1016/j.physletb.2021.136765. arXiv:2110.04179
15. **BESIII** Collaboration, M. Ablikim et al., Measurement of the absolute branching fraction for $\Lambda_c^+ \to \Lambda e^+\nu_e$. Phys. Rev. Lett. **115**(22), 221805 (2015). https://doi.org/10.1103/PhysRevLett.115.221805. arXiv:1510.02610
16. **BESIII** Collaboration, M. Ablikim et al., Measurement of the absolute branching fraction for $\Lambda_c^+ \to \Lambda\mu^+\nu_\mu$. Phys. Lett. B **767**, 42–47 (2017). https://doi.org/10.1016/j.physletb.2017.01.047. arXiv:1611.04382
17. **BESIII** Collaboration, M. Ablikim et al., Study of the semileptonic decay $\Lambda_c^+ \to \Lambda e^+\nu_e$. Phys. Rev. Lett. **129**(23), 231803 (2022). https://doi.org/10.1103/PhysRevLett.129.231803. arXiv:2207.14149
18. **BESIII** Collaboration, M. Ablikim et al., Study of $\Lambda_c^+ \to \Lambda\mu^+\nu_\mu$ and test of lepton flavor universality with $\Lambda_c^+ \to \Lambda\ell^+\nu_\ell$ decays. Phys. Rev. D **108**(3), L031105 (2023). https://doi.org/10.1103/PhysRevD.108.L031105. arXiv:2306.02624
19. H. Bahtiyar, $\Lambda_c \to \Lambda$ form factors in lattice QCD. Turk. J. Phys. **45**, 4 (2021). https://doi.org/10.3906/fiz-2104-28. arXiv:2107.13909
20. C. Farrell, S. Meinel, $\Xi_c \to \Xi$ form factors from lattice QCD with domain-wall quarks: a new piece in the puzzle of Ξ_c^0 decay rates. Phys. Rev. D **111**(11), 114521 (2025). https://doi.org/10.1103/35c9-kbvr. arXiv:2504.07302
21. T.M. Aliev, S. Bilmis, M. Savci, $\Xi_c \to \Xi$ Semileptonic Decays: An LCSR View on the Experiment-Lattice Tension. arXiv:2509.10181
22. P. Ball, V.M. Braun, E. Gardi, Distribution amplitudes of the Λ_b baryon in QCD. Phys. Lett. B **665**, 197–204 (2008). https://doi.org/10.1016/j.physletb.2008.06.004. arXiv:0804.2424
23. A. Ali, C. Hambrock, A.Y. Parkhomenko, W. Wang, Light-cone distribution amplitudes of the ground state bottom baryons in HQET. Eur. Phys. J. C **73**(2), 2302 (2013). https://doi.org/10.1140/epjc/s10052-013-2302-4. arXiv:1212.3280
24. **Particle Data Group** Collaboration, S. Navas et al., Review of particle physics. Phys. Rev. D **110**(3), 030001 (2024). https://doi.org/10.1103/PhysRevD.110.030001

25. S. Groote, J.G. Korner, O.I. Yakovlev, QCD sum rules for heavy baryons at next-to-leading order in α_S. Phys. Rev. D **55**, 3016–3026 (1997). https://doi.org/10.1103/PhysRevD.55.3016. arXiv:hep-ph/9609469
26. C. Bourrely, I. Caprini, L. Lellouch, Model-independent description of $B \to \pi l \nu$ decays and a determination of $|V_{ub}|$. Phys. Rev. D **79**, 013008 (2009). https://doi.org/10.1103/PhysRevD.82.099902. arXiv:0807.2722. [Erratum: Phys. Rev. D **82**, 099902 (2010)]
27. **ARGUS** Collaboration, H. Albrecht et al., Observations of Λ_c^+ semileptonic decay. Phys. Lett. B **269**, 234–242 (1991). https://doi.org/10.1016/0370-2693(91)91480-J
28. **CLEO** Collaboration, T. Bergfeld et al., Study of the decay $\Lambda_c^+ \Lambda \ell^+ \nu_\ell$. Phys. Lett. B **323**, 219–226 (1994). https://doi.org/10.1016/0370-2693(94)90295-X. arXiv:hep-ph/9403326