Semileptonic decays of Λ_b baryons

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Eur. Phys. J. C (2022) 82:951, *arXiv*:2406.00353

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洛阳，2024 年 11 月 10 日

HENAN NORMAL UNIVERSITY

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Outline

1. Introduction
2. Form factors of $\Lambda_b \to \Lambda_c^{(*)}$
   - Light-cone sum rule calculations of form factors
   - An overview of Λ_b LCDAs
3. Applications on semileptonic decays
4. Conclusions

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Introduction

Investigation of the semileptonic decay modes of Λ_b baryon provide us:

- Determine the CKM matrix element V_{cb}、 V_{ub} on baryon sectors;
- Know more about the inner structure of heavy flavor baryons;
- Test the Standard Model and explore the New Physics and beyond.

Moreover, we need the non-pertubative parameters form factors, the reason why we choose Λ_b baryon as the object is that:

- Λ_b semileptonic decays are clear channel;
- In bottom baryon section, its decay modes are abundantent, 75 decay modes listed in PDG.

- Recently experiment result: LHCb PRL 128,191803 (2022)

$$\mathcal{B}r(\Lambda_b^0 \to \Lambda_c^+ \tau^- \bar{\nu}_\tau) = (1.50 \pm 0.16_{\rm stat} \pm 0.25_{\rm syst} \pm 0.23)\%$$

$$\mathcal{R}(\Lambda_c^+) \equiv \mathcal{B}r(\Lambda_b^0 \to \Lambda_c^+ \tau^- \bar{\nu}_\tau)/\mathcal{B}r(\Lambda_b^0 \to \Lambda_c^+ \mu^- \bar{\nu}_\mu) = (0.242 \pm 0.026 \pm 0.040).$$

- PDG:

CDF Phys. Rev. D 79, 032001 (2009)

$$\mathcal{B}r(\Lambda_b^0 \to \Lambda_c^+ \ell^- \bar{\nu}_\ell) = (6.2^{+1.4}_{-1.3}) \times 10^{-2}$$

$$\mathcal{B}r(\Lambda_b^0 \to \Lambda_c(2595)^+ \ell^- \bar{\nu}_\ell) = (7.9^{+4.0}_{-3.5}) \times 10^{-3}$$

- Recent 5 years PDG refs. on Λ_b:

Λ_b^0 REFERENCES

AAIJ	23BB	PRL 131 151801	R. Aaij *et al.*	(LHCb Collab.)
AAIJ	23K	JHEP 2307 075	R. Aaij *et al.*	(LHCb Collab.)
AAIJ	22K	PRL 128 191803	R. Aaij *et al.*	(LHCb Collab.)
AAIJ	22M	PR D105 L051104	R. Aaij *et al.*	(LHCb Collab.)
AAIJ	22R	JHEP 2203 153	R. Aaij *et al.*	(LHCb Collab.)
AAIJ	21AD	PR D104 112008	R. Aaij *et al.*	(LHCb Collab.)
AAIJ	21AJ	JHEP 2110 060	R. Aaij *et al.*	(LHCb Collab.)
AAIJ	21B	PL B815 136172	R. Aaij *et al.*	(LHCb Collab.)
AAIJ	21R	JHEP 2105 095	R. Aaij *et al.*	(LHCb Collab.)
AAIJ	20AB	PR D102 051101	R. Aaij *et al.*	(LHCb Collab.)
AAIJ	20AK	PR D102 112012	R. Aaij *et al.*	(LHCb Collab.)
AAIJ	20M	JHEP 2005 040	R. Aaij *et al.*	(LHCb Collab.)
AAIJ	20O	JHEP 2006 110	R. Aaij *et al.*	(LHCb Collab.)
SIRUNYAN	20H	PL B802 135203	A.M. Sirunyan *et al.*	(CMS Collab.)
AAIJ	19AH	EPJ C79 745	R. Aaij *et al.*	(LHCb Collab.)
AAIJ	19AN	JHEP 1909 028	R. Aaij *et al.*	(LHCb Collab.)
AAIJ	19F	JHEP 1903 126	R. Aaij *et al.*	(LHCb Collab.)
AAIJ	19Z	PRL 123 031801	R. Aaij *et al.*	(LHCb Collab.)
AAIJ	18AF	JHEP 1808 131	R. Aaij *et al.*	(LHCb Collab.)
AAIJ	18AG	JHEP 1808 039	R. Aaij *et al.*	(LHCb Collab.)
AAIJ	18AO	JHEP 1809 145 (errat.)	R. Aaij *et al.*	(LHCb Collab.)
AAIJ	18AP	JHEP 1809 146	R. Aaij *et al.*	(LHCb Collab.)
AAIJ	18AW	PL B784 101	R. Aaij *et al.*	(LHCb Collab.)
AAIJ	18AX	PL B787 124	R. Aaij *et al.*	(LHCb Collab.)
AAIJ	18Q	JHEP 1802 098	R. Aaij *et al.*	(LHCb Collab.)
PDG	18	PR D98 030001	M. Tanabashi *et al.*	(PDG Collab.)
SIRUNYAN	18BY	EPJ C78 457	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	18R	PR D97 072010	A.M. Sirunyan *et al.*	(CMS Collab.)

- Theoretical studies on Λ_b semileptonic decays

  $\Lambda_b \to \Lambda_c$: light-front quark model; Lattice QCD; heavy quark effective theory; covariant confinded quark model;QCD sum rule; relativistic quark model; Hypercentral sonstituent quark model *etc*.

  $\Lambda_b \to \Lambda_c(2595)$: light-front quark model; Lattice QCD; heavy quark symmetry; covariant confinede quark model; constituent quark model; Bakamjian-Thomas approach with quark model *etc*.

Outline

Form Factors within LCSRs

For the calculations of Λ_b weak decay form factors, we use the light-cone QCD sum rule approach.

- The starting point of LCSR is the weak decay correlator:

$$T_\mu(p, q) = i \int d^4x e^{ip\cdot x} \langle 0 | \mathcal{T}\{j_{\Lambda_c}(x), j_\mu(0)\} | \Lambda_b(p+q) \rangle.$$

- There are two currents in the above correlator:

  Hadron interpolating current j_{Λ_c} and weak decay current j_μ (V-A).

- Positive parity and negative Λ_c are related by a γ_5 factor. Therefore, we can insert both the positive and negative parity Λ_c and $\Lambda_c(2595)^+$ states in the correlator.

- The next step is calculating the correlator on both hadronic and QCD level.

  The hadronic level representation can be represented as:

$$T_\mu(p,q) = \frac{\langle 0|j^i_{\Lambda_c}(x)|\Lambda_c(p)\rangle\langle\Lambda_c(p)|j_\mu(0)|\Lambda_b(p+q)\rangle}{M^2_{\Lambda_c}-p^2} + \frac{\langle 0|j^i_{\Lambda_c^*}(x)|\Lambda_c^*(p)\rangle\langle\Lambda_c^*(p)|j_\mu(0)|\Lambda_b(p+q)\rangle}{M^2_{\Lambda_c^*}-p^2} + \text{higher states.}$$

  Now, the correlator contains both the contribution of Λ_c and $\Lambda_c(2595)^+$ on hadronic side.

- For $\Lambda_b \to \Lambda_c\ (\frac{1}{2}^+ \to \frac{1}{2}^+)$:

$$\begin{aligned}\langle \Lambda_c|\bar{c}\gamma_\mu(1-\gamma_5)b|\Lambda_b\rangle =& \bar{u}(p,s_1)[\gamma_\mu f_1(q^2) + i\frac{f_2(q^2)}{M_{\Lambda_b}}\sigma_{\mu\nu}q^\nu + \frac{f_3(q^2)}{M_{\Lambda_b}}q_\mu]u_{\Lambda_b}(p+q,s_2)\\ &-\bar{u}(p,s_1)[\gamma_\mu g_1(q^2) + i\frac{g_2(q^2)}{M_{\Lambda_b}}\sigma_{\mu\nu}q^\nu + \frac{g_3(q^2)}{M_{\Lambda_b}}q_\mu]\gamma_5 u_{\Lambda_b}(p+q,s_2).\end{aligned}$$

- For the $\Lambda_b^0 \to \Lambda_c^*\ (\frac{1}{2}^+ \to \frac{1}{2}^-)$:

$$\begin{aligned}\langle \Lambda_c^*|\bar{c}\gamma_\mu(1-\gamma_5)b|\Lambda_b\rangle =& \bar{u}(p,s_1)[\gamma_\mu f_1^*(q^2) + i\frac{f_2^*(q^2)}{M_{\Lambda_b}}\sigma_{\mu\nu}q^\nu + \frac{f_3^*(q^2)}{M_{\Lambda_b}}q_\mu]\gamma_5 u_{\Lambda_b}(p+q,s_2)\\ &-\bar{u}(p,s_1)[\gamma_\mu g_1^*(q^2) + i\frac{g_2^*(q^2)}{M_{\Lambda_b}}\sigma_{\mu\nu}q^\nu + \frac{g_3^*(q^2)}{M_{\Lambda_b}}q_\mu]u_{\Lambda_b}(p+q,s_2).\end{aligned}$$

- Another form often used in Lattice QCD:

$$
\begin{aligned}
&\langle\Lambda_c^*|\bar{c}\gamma_\mu(1-\gamma_5)b|\Lambda_b\rangle \\
&\quad = \bar{u}(p,s_1)\gamma_5\{f_0^*(M_{\Lambda_b}+M_{\Lambda_c^*})\frac{q^\mu}{q^2} + f_+^*\frac{M_{\Lambda_b}-M_{\Lambda_c^*}}{s_-}[p^\mu + p'^\mu - (M_{\Lambda_b}^2 - M_{\Lambda_c}^2)\frac{q^\mu}{q^2}] \\
&\quad + f_\perp^*[\gamma^\mu + \frac{2M_{\Lambda_c^*}}{s_-}p^\mu - \frac{2M_{\Lambda_b}}{s_-}p'^\mu] + g_0^*\gamma_5(M_{\Lambda_b}-M_{\Lambda_c^*})\frac{q^\mu}{q^2} + g_+^*\gamma_5\frac{M_{\Lambda_b}+M_{\Lambda_c^*}}{s_+}[p^\mu + p'^\mu \\
&\quad - (M_{\Lambda_b}^2 - M_{\Lambda_c^*}^2)\frac{q^\mu}{q^2}] + g_\perp^*\gamma_5[\gamma^\mu - \frac{2M_{\Lambda_c^*}}{s_+}p^\mu - \frac{2M_{\Lambda_b}}{s_+}p'^\mu]\}u_{\Lambda_b}(p',s_2)
\end{aligned}
$$

- The transformation relations of these two types form factors are:

$$f_0^* = \frac{q^2}{M_{\Lambda_b}(M_{\Lambda_b}+M_{\Lambda_c^*})}f_3^* - f_1^*;$$

$$f_+^* = -\frac{q^2}{M_{\Lambda_b}(M_{\Lambda_b}-M_{\Lambda_c^*})}f_2^* - f_1^*;$$

$$f_\perp^* = \frac{M_{\Lambda_c^*}-M_{\Lambda_b}}{M_{\Lambda_b}}f_2^* - f_1^*;$$

$$g_0^* = -\frac{q^2}{M_{\Lambda_b}(M_{\Lambda_b}-M_{\Lambda_c^*})}g_3^* - g_1^*;$$

$$g_+^* = \frac{q^2}{M_{\Lambda_b}(M_{\Lambda_b}+M_{\Lambda_c^*})}g_2^* - g_1^*;$$

$$g_\perp^* = \frac{M_{\Lambda_c^*}+M_{\Lambda_b}}{M_{\Lambda_b}}g_2^* - g_1^*.$$

(1) Scalar: $j^S_{\Lambda_c}(x) = \epsilon_{ijk}[u(x)\,Cd(x)]\gamma_5\,c(x)$, no contributions in sum rules;

(2) Pseudoscalar: $j^P_{\Lambda_c}(x) = \epsilon_{ijk}[u(x)\,C\gamma_5\,d(x)]\,c(x)$;

(3) Axial-vector: $j^A_{\Lambda_c}(x) = \epsilon_{ijk}[u(x)\,C\gamma_5\gamma_\nu\,d(x)]\gamma^\nu\,c(x)$.

- For the pseudoscalar current $j^P_{\Lambda_c}$, the correlation function $T_\mu(p, q)$ is given by:

$$T_\mu(p, q) = i\int d^4x e^{ip\cdot x}\langle 0|\mathcal{T}\{j^P_{\Lambda_c}(x), j_\mu(0)\}|\Lambda_b(p+q)\rangle$$

$$= i\int d^4x e^{ip\cdot x}(C\gamma_5)_{\alpha\beta}S_{\sigma\tau}(x)[\gamma_\mu(1-\gamma_5)]_{\tau\gamma}\langle 0|\epsilon_{ijk}u^{iT}_\alpha(x)\,d^j_\beta(x)\,b^k_\gamma(0)|\Lambda_b(p+q)\rangle.$$

- For the axial-vector current $j^A_{\Lambda_c}$:

$$T_\mu(p, q) = i\int d^4x e^{ip\cdot x}\langle 0|\mathcal{T}\{j^A_{\Lambda_c}(x), j_\mu(0)\}|\Lambda_b(p+q)\rangle$$

$$= i\int d^4x e^{ip\cdot x}(C\gamma_5\gamma_\nu)_{\alpha\beta}S_{\sigma\tau}(x)[\gamma_\mu(1-\gamma_5)]_{\tau\gamma}\gamma^\nu_{\rho\sigma}\langle 0|\epsilon_{ijk}u^{iT}_\alpha(x)\,d^j_\beta(x)\,b^k_\gamma(0)|\Lambda_b(p+q)\rangle.$$

Definition of Λ_b LCDAs

- The red part matrix element $\langle 0|\epsilon_{ijk} u_\alpha^{iT}(x)\, d_\beta^j(x)\, b_\gamma^k(0)|\Lambda_b(p+q)\rangle$ can be defined by:

$$\frac{1}{v_+}\langle 0|\left[u(t_1)\mathcal{C}\gamma_5 \not{n} d(t_2)\right] b_\gamma|\Lambda_b\rangle = \psi^n(t_1,t_2) f_{\Lambda_b}^{(1)} u_\gamma,$$

$$\frac{i}{2}\langle 0|\left[u(t_1)\mathcal{C}\gamma_5 \sigma_{\bar{n}n} d(t_2)\right] b_\gamma|\Lambda_b\rangle = \psi^{n\bar{n}}(t_1,t_2) f_{\Lambda_b}^{(2)} u_\gamma,$$

$$\langle 0|\left[u(t_1)\mathcal{C}\gamma_5 d(t_2)\right] b_\gamma|\Lambda_b\rangle = \psi^{\mathbb{1}}(t_1,t_2) f_{\Lambda_b}^{(2)} u_\gamma,$$

$$v_+\langle 0|\left[u(t_1)\mathcal{C}\gamma_5 \not{\bar{n}} d(t_2)\right] b_\gamma|\Lambda_b\rangle = \psi^{\bar{n}}(t_1,t_2) f_{\Lambda_b}^{(1)} u_\gamma.$$

$$\begin{aligned}
&\epsilon^{ijk}\langle 0|u_\alpha^i(t_1 n)\, d_\beta^j(t_2 n)\, b_\gamma^k|\Lambda_b\rangle \\
&= \frac{1}{8} v_+ f_{\Lambda_b}^{(1)} \Psi^n(t_1,t_2)(\not{\bar{n}}\gamma_5 C^T)_{\beta\alpha} u_{\Lambda_b\gamma}(v) \\
&+ \frac{1}{4} f_{\Lambda_b}^{(2)} \Psi^{\mathbb{1}}(t_1,t_2)(\gamma_5 C^T)_{\beta\alpha} u_{\Lambda_b\gamma}(v) \\
&- \frac{1}{8} f_{\Lambda_b}^{(2)} \Psi^{n\bar{n}}(t_1,t_2)(i\sigma_{n\bar{n}}\gamma_5 C^T)_{\beta\alpha} u_{\Lambda_b\gamma}(v) \\
&+ \frac{1}{8}\frac{1}{v_+} f_{\Lambda_b}^{(1)} \Psi^{\bar{n}}(t_1,t_2)(\not{n}\gamma_5 C^T)_{\beta\alpha} u_{\Lambda_b\gamma}(v).
\end{aligned}$$

- For the $\Lambda_b \to \Lambda_c$ form factors, we use Type V LCDAs of Λ_b in LCSRs:
- Type V:

$$
\begin{aligned}
\tilde{\psi}_2(\omega, u) =& \omega^2 u(1-u)[\frac{1}{\epsilon_0^4} e^{-\omega/\epsilon_0} + a_2 C_2^{3/2}(2u-1)\frac{1}{\epsilon_1^4} e^{-\omega/\epsilon_1}], \\
\tilde{\psi}_3^s(\omega, u) =& \frac{\omega}{2\epsilon_3^3} e^{-\omega/\epsilon_3}, \\
\tilde{\psi}_3^\sigma(\omega, u) =& \frac{\omega}{2\epsilon_3^3}(2u-1) e^{-\omega/\epsilon_3}, \\
\tilde{\psi}_4(\omega, u) =& 5\mathcal{N}^{-1} \int_{\omega/2}^{s_0^{\Lambda_b}} ds e^{-s/\tau}(s-\omega/2)^3
\end{aligned}
$$

- And other four Λ_b LCDAs models are also used to calculate $\Lambda_b \to \Lambda_c(2595)^+$ form factors in LCSRs:

- Type I:

$$\tilde{\psi}_2(\omega,u) = \omega^2 u(1-u) \sum_{n=0}^{2} \frac{a_n}{\epsilon_n^4} \frac{C_n^{3/2}(2u-1)}{|C_n^{3/2}|^2} e^{-\omega/\epsilon_n},$$

$$\tilde{\psi}_3(\omega,u) = \frac{\omega}{2} \sum_{n=0}^{2} \frac{a_n}{\epsilon_n^3} \frac{C_n^{1/2}(2u-1)}{|C_n^{1/2}|^2} e^{-\omega/\epsilon_n},$$

$$\tilde{\psi}_4(\omega,u) = \sum_{n=0}^{2} \frac{a_n}{\epsilon_n^2} \frac{C_n^{1/2}(2u-1)}{|C_n^{1/2}|^2} e^{-\omega/\epsilon_n}.$$

- Type II:

$$\psi_2(\omega,u) = \frac{\omega^2 u(1-u)}{\omega_0^4} e^{-\omega/\omega_0}, \quad \psi_3^s(\omega,u) = \frac{\omega}{2\omega_0^3} e^{-\omega/\omega_0},$$

$$\psi_3^\sigma(\omega,u) = \frac{\omega(2u-1)}{2\omega_0^3} e^{-\omega/\omega_0}, \quad \psi_4(\omega,u) = \frac{1}{\omega_0^2} e^{-\omega/\omega_0},$$

- Type III:

$$\psi_2(\omega,u) = \frac{15\omega^2 u(1-u)(2\bar{\Lambda}-\omega)}{4\bar{\Lambda}^5}\theta(2\bar{\Lambda}-\omega),$$

$$\psi_3^s(\omega,u) = \frac{15\omega(2\bar{\Lambda}-\omega)^2}{16\bar{\Lambda}^5}\theta(2\bar{\Lambda}-\omega),$$

$$\psi_3^\sigma(\omega,u) = \frac{15\omega(2\bar{\Lambda}-\omega)^2(2u-1)}{8\bar{\Lambda}^5}\theta(2\bar{\Lambda}-\omega),$$

$$\psi_4(\omega,u) = \frac{5(2\bar{\Lambda}-\omega)^3}{8\bar{\Lambda}^5}\theta(2\bar{\Lambda}-\omega),$$

- Type IV:

$$\tilde{\psi}_2(\omega,u) = \frac{15}{2}\mathcal{N}^{-1}\omega^2(1-u)u \int_{\omega/2}^{s_0^{\Lambda_b}} ds e^{-s/\tau}(s-\omega/2),$$

$$\tilde{\psi}_3^s(\omega,u) = \frac{15}{4}\mathcal{N}^{-1}\omega \int_{\omega/2}^{s_0^{\Lambda_b}} ds e^{-s/\tau}(s-\omega/2)^2,$$

$$\tilde{\psi}_3^\sigma(\omega,u) = \frac{15}{4}\mathcal{N}^{-1}\omega(2u-1) \int_{\omega/2}^{s_0^{\Lambda_b}} ds e^{-s/\tau}(s-\omega/2)^2,$$

$$\tilde{\psi}_4(\omega,u) = 5\mathcal{N}^{-1} \int_{\omega/2}^{s_0^{\Lambda_b}} ds e^{-s/\tau}(s-\omega/2)^3,$$

- There are twelves Lorentz structures and corresponding coefficients both on hadronic and QCD side in total:

$$\begin{aligned}T_\mu(p,q) =&\Pi_{v_\mu} v_\mu + \Pi_{\gamma_\mu}\gamma_\mu + \Pi_{q_\mu} q_\mu + \Pi_{v_\mu \not{q}} v_\mu \not{q} + \Pi_{\gamma_\mu \not{q}}\gamma_\mu \not{q} + \Pi_{q_\mu \not{q}} q_\mu \not{q} \\ &+ \Pi_{v_\mu\gamma_5} v_\mu\gamma_5 + \Pi_{\gamma_\mu\gamma_5}\gamma_\mu\gamma_5 + \Pi_{q_\mu\gamma_5} q_\mu\gamma_5 + \Pi_{v_\mu\not{q}\gamma_5} v_\mu\not{q}\gamma_5 + \Pi_{\gamma_\mu\not{q}\gamma_5}\gamma_\mu\not{q}\gamma_5 \\ &+ \Pi_{q_\mu\not{q}\gamma_5} q_\mu\not{q}\gamma_5 .\end{aligned}$$

  On the hadronic side, the coefficients Π_{Γ_i} contain form factors;

  On the QCD side, they are functions of momentum transfer square q^2.

- Next, we will extracting the form factors from the two side use of correlator.

  1. Matching the Lorentz structures on both side;
  2. Using Borel transformation to suppress the higher excited and continuum states.
  3. Obtain the form factors.

- Form factors deduced from LCSR only functions on $q^2 < 2.5$ GeV^2, we need to extrapolate them to the entire physical regions.
- The following fitting formula is used to do this manipulation:

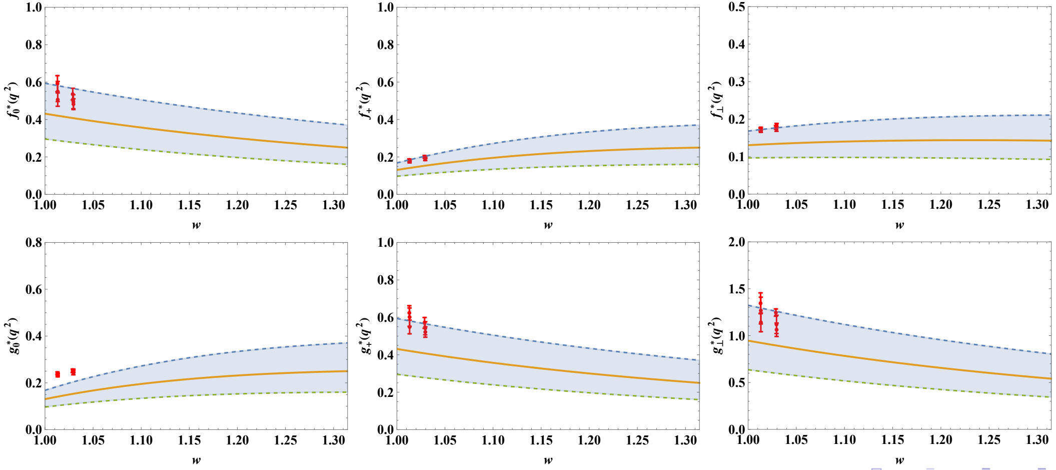
$$f_i(q^2)/g_i(q^2) = \frac{f_i(0)/g_i(0)}{1 - q^2/M_{B_c}^2}\Big\{b_1\left[z(q^2) - z(0)\right] + b_2\left[z(q^2)^2 - z(0)^2\right] + 1\Big\}.$$

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

where t_+ and t_0 are given by:

$$t_+ = \left(M_{\Lambda_b} + M_{\Lambda_c^*}\right)^2,$$
$$t_0 = \left(M_{\Lambda_b} + M_{\Lambda_c^*}\right) \cdot \left(\sqrt{M_{\Lambda_b}} - \sqrt{M_{\Lambda_c^*}}\right)^2.$$

- Fitting the form factors on the data range $-15\ \mathrm{GeV}^2 < q^2 < 2.5\ \mathrm{GeV}^2$, q^2 larger than $2.5\ \mathrm{GeV}^2$ sum rule will break down.
- Form factors on the whole physical regions $m_\ell^2 \leq q^2 \leq (M_{\Lambda_b} - M_{\Lambda_c})^2$: LQCD(disipative points): w near 1.01 and 1.03. LCSR(shadde bands): $q^2 < 2.5\ \mathrm{GeV}^2$, $w \gtrsim 1.23$.



- For the weak decay form factors of $\Lambda_b \to \Lambda_c$, they have the relations:

$$f_1(q^2) = g_1(q^2), f_2(q^2) = f_3(q^2) = g_2(q^2) = g_3(q^2)$$

.

- Form factors of $\Lambda_b^0 \to \Lambda_c^+$ by using Type V Λ_b LCDAs and $j^P_{\Lambda_c}$:

$F_i(q^2)$	$F_i(0)$	b_1	b_2
$f_1(q^2)$	$0.534^{+0.060}_{-0.074}$	$-2.883^{+0.779}_{-1.619}$	$-15.991^{+9.571}_{-3.108}$
$f_2(q^2)$	$-0.054^{+0.013}_{-0.011}$	$-11.474^{+2.262}_{-2.369}$	$34.934^{+21.608}_{-12.878}$

- Form factors of $\Lambda_b^0 \to \Lambda_c^+$ by using Type V Λ_b LCDAs and $j^A_{\Lambda_c}$:

$$f_1(0) = g_1(0) = 0.644^{+0.175}_{-0.352}$$

$$f_2(0) = f_3(0) = g_2(0) = g_3(0) = -0.100^{+0.061}_{-0.039}$$

- Form Factors within five different Λ_b LCDAs models for $\Lambda_b \to \Lambda_c(2595)^+$:

		$j^P_{\Lambda_c}$			$j^A_{\Lambda_c}$		
Λ_b LCDAs	$f_i^*(q^2)$	$f_i^*(0)$	b_1	b_2	$f_i^*(0)$	b_1	b_2
Type I	$f_1^*(q^2)$	$0.087^{+0.045}_{-0.030}$	$3.135^{+1.052}_{-1.827}$	$-31.005^{+5.275}_{-1.394}$	$-0.250^{+0.090}_{-0.121}$	$-2.070^{+2.287}_{-2.284}$	$-18.173^{+13.416}_{-11.995}$
	$f_2^*(q^2)$	$-0.070^{+0.017}_{-0.013}$	$-4.131^{+4.375}_{-4.592}$	$-13.180^{+29.470}_{-19.423}$	$0.199^{+0.098}_{-0.073}$	$-15.683^{+2.208}_{-2.070}$	$70.549^{+16.979}_{-17.481}$
Type II	$f_1^*(q^2)$	$0.023^{+0.010}_{-0.008}$	$-6.110^{+0.268}_{-0.504}$	$5.244^{+2.826}_{-1.124}$	$-0.122^{+0.037}_{-0.046}$	$-9.056^{+0.703}_{-0.863}$	$27.885^{+5.771}_{-4.519}$
	$f_2^*(q^2)$	$-0.027^{+0.008}_{-0.010}$	$-21.246^{+0.641}_{-0.728}$	$118.441^{+6.101}_{-5.297}$	$0.068^{+0.027}_{-0.022}$	$-20.416^{+0.595}_{-0.189}$	$110.738^{+13.804}_{-4.832}$
Type III	$f_1^*(q^2)$	$0.136^{+0.064}_{-0.047}$	$-8.401^{+0.612}_{-0.707}$	$17.115^{+5.484}_{-4.765}$	$-0.150^{+0.053}_{-0.070}$	$-16.659^{+0.475}_{-0.441}$	$83.488^{+3.694}_{-4.134}$
	$f_2^*(q^2)$	$-0.168^{+0.055}_{-0.068}$	$-24.277^{+1.158}_{-0.995}$	$143.305^{+9.632}_{-11.322}$	$0.075^{+0.043}_{-0.032}$	$-33.299^{+0.269}_{-0.238}$	$231.369^{+2.023}_{-2.507}$
Type IV	$f_1^*(q^2)$	$0.024^{+0.012}_{-0.008}$	$-8.513^{+0.619}_{-0.481}$	$19.595^{+3.362}_{-4.418}$	$-0.107^{+0.036}_{-0.047}$	$-14.680^{+0.503}_{-0.560}$	$68.608^{+4.327}_{-3.907}$
	$f_2^*(q^2)$	$-0.030^{+0.010}_{-0.012}$	$-24.590^{+0.657}_{-0.628}$	$147.657^{+5.714}_{-6.045}$	$0.049^{+0.026}_{-0.019}$	$-28.373^{+0.186}_{-0.151}$	$183.921^{+1.035}_{-1.448}$
Type V	$f_1^*(q^2)$	$0.057^{+0.022}_{-0.016}$	$-0.521^{+0.339}_{-0.753}$	$-24.239^{+2.607}_{-0.144}$	$-0.466^{+0.103}_{-0.116}$	$4.634^{+1.186}_{-1.628}$	$-50.227^{+5.668}_{-2.680}$
	$f_2^*(q^2)$	$-0.056^{+0.014}_{-0.022}$	$-11.977^{+1.294}_{-1.584}$	$40.732^{+12.077}_{-9.441}$	$0.406^{+0.092}_{-0.085}$	$-9.206^{+1.375}_{-1.750}$	$20.098^{+12.583}_{-9.251}$

Outline

- Differential decay widths of $\Lambda_b \to \Lambda_c(2595)\ell\bar{\nu}_\ell$ $(\frac{1}{2}^+ \to \frac{1}{2}^-)$:

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2|V_{\mathrm{CKM}}|^2}{192\pi^3}\frac{M_{\Lambda_b}^2 - M_{\Lambda_c^*}^2}{2M_{\Lambda_b}^3}\frac{(q^2-m_\ell^2)^2}{q^2}\mathcal{H}_{\frac{1}{2}\to-\frac{1}{2}}.$$

- Helicity amplitudes:

$$\mathcal{H}_{\frac{1}{2}\to-\frac{1}{2}} =|H_{\frac{1}{2},0}|^2 + |H_{-\frac{1}{2},0}|^2 + |H_{\frac{1}{2},1}|^2 + |H_{-\frac{1}{2},-1}|^2 + \frac{m_\ell^2}{2q^2}\Big(3|H_{\frac{1}{2},t}|^2 + 3|H_{-\frac{1}{2},t}|^2 + |H_{\frac{1}{2},1}|^2 + |H_{-\frac{1}{2},-1}|^2 + |H_{\frac{1}{2},0}|^2 + |H_{-\frac{1}{2},0}|^2\Big).$$

- The relations from form factors to helicity amplitudes:

$$H^V_{\frac{1}{2},0} = \sqrt{\frac{Q_+}{q^2}}\left[f_1^*(q^2)M_- + f_2^*(q^2)\frac{q^2}{M_{\Lambda_b}}\right], \quad H^A_{\frac{1}{2},0} = \sqrt{\frac{Q_-}{q^2}}\left[M_+ g_1^*(q^2) - \frac{q^2}{M_{\Lambda_b}}g_2^*(q^2)\right],$$

$$H^V_{\frac{1}{2},1} = \sqrt{2Q_+}\left[-f_1^*(q^2) - \frac{M_-}{M_{\Lambda_b}}f_2^*(q^2)\right], \quad H^A_{\frac{1}{2},1} = \sqrt{2Q_-}\left[-g_1^*(q^2) + \frac{M_+}{M_{\Lambda_b}}g_2^*(q^2)\right],$$

$$H^V_{\frac{1}{2},t} = \sqrt{\frac{Q_-}{q^2}}\left[M_+ f_1^*(q^2) - \frac{q^2}{M_{\Lambda_b}}f_3^*(q^2)\right], \quad H^A_{\frac{1}{2},t} = \sqrt{\frac{Q_+}{q^2}}\left[M_- g_1^*(q^2) + \frac{q^2}{M_{\Lambda_b}}g_3^*(q^2)\right].$$

- Branching ratios of $\Lambda_b^0 \to \Lambda_c^+ \ell^- \bar{\nu}_\ell$:($j^1_{\Lambda_c} = j^P_{\Lambda_c}, j^2_{\Lambda_c} = j^A_{\Lambda_c}$)

Table 4 The decay widths and branching fractions compared with other models. The first and second values in the Γ and $\mathcal{B}r$ columns of $\Lambda_b^0 \to \Lambda_c^+ \ell^- \bar{\nu}_\ell$ stand for the $\Lambda_b^0 \to \Lambda_c^+ e^- \bar{\nu}_e$ and $\Lambda_b^0 \to \Lambda_c^+ \mu^- \bar{\nu}_\mu$, respectively. All the data listed are the central values

References	Decay widths $\Gamma(\times 10^{10}\ \mathrm{s}^{-1})$ $\Gamma(\Lambda_b^0 \to \Lambda_c^+ \ell^- \bar{\nu}_\ell)$	$\Gamma(\Lambda_b^0 \to \Lambda_c^+ \tau^- \bar{\nu}_\tau)$	Branching fractions $(\times 10^{-2})$ $\mathcal{B}r(\Lambda_b^0 \to \Lambda_c^+ \ell^- \bar{\nu}_\ell)$	$\mathcal{B}r(\Lambda_b^0 \to \Lambda_c^+ \tau^- \bar{\nu}_\tau)$
LHCb [1]	–	–	–	1.50
DELPHI [2]	–	–	5.0	–
CDF [3]	–	–	7.3	2.0
[5]	5.4	–	–	–
[6]	3.52	1.12	6.04	1.87
[7]	–	–	6.2, 6.3	–
[8]	–	–	5.59, 5.57	1.54
[9]	5.0, 7.7	–	–	–
[10]	–	–	6.47, 6.45	1.97
[11]	3.61	1.2	–	–
[15]	4.42,4.41	1.39	6.48, 6.46	2.03
[16]	–	–	6.9	2.0
[18]	4.11	–	6.04	–
[21]	–	–	5.34	1.78
[57]	5.9	–	–	–
[58]	5.1	–	–	–
[43]	5.39	–	–	–
[59]	6.09	–	–	–
[60]	5.01, 7.61, 2.73	–	–	
[61]	–	–	6.3	–
[62]	5.82	–	–	–
[63]	5.02, 5.64	–	6.2, 6.9	–
[64]	4.50	–	6.61	–
This work $j^1_{\Lambda_c}$	3.95, 3.94	1.08	5.81, 5.79	1.59
This work $j^2_{\Lambda_c}$	4.60, 4.57	1.09	6.76, 6.73	1.61

- Branching rations of $\Lambda_b^0 \to \Lambda_c(2595)^+ \ell^- \bar{\nu}_\ell$:

Λ_b LCDAs model	Decay channel	Decay width Γ ($\times\lvert V_{cb}\rvert^2 \times 10^{-12}$ GeV)		Branching fraction($\times 10^{-3}$)	
		$j^P_{\Lambda_c}$	$j^A_{\Lambda_c}$	$j^P_{\Lambda_c}$	$j^A_{\Lambda_c}$
Type I	$\Lambda_b^0 \to \Lambda_c(2595)^+ e^- \bar{\nu}_e$	$0.247^{+0.356}_{-0.142}$	$2.336^{+2.441}_{-1.300}$	$0.918^{+1.324}_{-0.528}$	$8.692^{+9.082}_{-4.836}$
	$\Lambda_b^0 \to \Lambda_c(2595)^+ \mu^- \bar{\nu}_\mu$	$0.245^{+0.354}_{-0.141}$	$2.325^{+2.428}_{-1.293}$	$0.913^{+1.317}_{-0.526}$	$8.649^{+9.033}_{-4.811}$
	$\Lambda_b^0 \to \Lambda_c(2595)^+ \tau^- \bar{\nu}_\tau$	$0.046^{+0.077}_{-0.027}$	$0.468^{+0.439}_{-0.249}$	$0.172^{+0.285}_{-0.102}$	$1.741^{+1.632}_{-0.926}$
Type II	$\Lambda_b^0 \to \Lambda_c(2595)^+ e^- \bar{\nu}_e$	$0.021^{+0.023}_{-0.011}$	$0.784^{+0.671}_{-0.391}$	$0.079^{+0.084}_{-0.043}$	$2.917^{+2.496}_{-1.453}$
	$\Lambda_b^0 \to \Lambda_c(2595)^+ \mu^- \bar{\nu}_\mu$	$0.021^{+0.023}_{-0.011}$	$0.781^{+0.668}_{-0.389}$	$0.078^{+0.084}_{-0.042}$	$2.905^{+2.486}_{-1.448}$
	$\Lambda_b^0 \to \Lambda_c(2595)^+ \tau^- \bar{\nu}_\tau$	$0.004^{+0.004}_{-0.002}$	$0.201^{+0.167}_{-0.098}$	$0.015^{+0.016}_{-0.008}$	$0.747^{+0.622}_{-0.365}$
Type III	$\Lambda_b^0 \to \Lambda_c(2595)^+ e^- \bar{\nu}_e$	$0.770^{+0.862}_{-0.434}$	$1.499^{+1.617}_{-0.838}$	$2.864^{+3.206}_{-1.615}$	$5.576^{+6.015}_{-3.117}$
	$\Lambda_b^0 \to \Lambda_c(2595)^+ \mu^- \bar{\nu}_\mu$	$0.766^{+0.858}_{-0.432}$	$1.494^{+1.611}_{-0.835}$	$2.850^{+3.190}_{-1.608}$	$5.558^{+5.995}_{-3.106}$
	$\Lambda_b^0 \to \Lambda_c(2595)^+ \tau^- \bar{\nu}_\tau$	$0.148^{+0.165}_{-0.083}$	$0.423^{+0.439}_{-0.231}$	$0.550^{+0.615}_{-0.309}$	$1.572^{+1.633}_{-0.861}$
Type IV	$\Lambda_b^0 \to \Lambda_c(2595)^+ e^- \bar{\nu}_e$	$0.025^{+0.028}_{-0.014}$	$0.754^{+0.759}_{-0.407}$	$0.092^{+0.104}_{-0.052}$	$2.804^{+2.824}_{-1.513}$
	$\Lambda_b^0 \to \Lambda_c(2595)^+ \mu^- \bar{\nu}_\mu$	$0.024^{+0.028}_{-0.014}$	$0.751^{+0.757}_{-0.405}$	$0.091^{+0.103}_{-0.052}$	$2.794^{+2.814}_{-1.508}$
	$\Lambda_b^0 \to \Lambda_c(2595)^+ \tau^- \bar{\nu}_\tau$	$0.005^{+0.005}_{-0.003}$	$0.214^{+0.208}_{-0.113}$	$0.018^{+0.020}_{-0.010}$	$0.795^{+0.775}_{-0.421}$
Type V	$\Lambda_b^0 \to \Lambda_c(2595)^+ e^- \bar{\nu}_e$	$0.111^{+0.102}_{-0.054}$	$6.418^{+3.253}_{-2.324}$	$0.414^{+0.380}_{-0.200}$	$23.875^{+12.101}_{-8.647}$
	$\Lambda_b^0 \to \Lambda_c(2595)^+ \mu^- \bar{\nu}_\mu$	$0.111^{+0.102}_{-0.053}$	$6.380^{+3.232}_{-2.310}$	$0.412^{+0.378}_{-0.199}$	$23.735^{+12.024}_{-8.593}$
	$\Lambda_b^0 \to \Lambda_c(2595)^+ \tau^- \bar{\nu}_\tau$	$0.020^{+0.020}_{-0.010}$	$1.049^{+0.490}_{-0.354}$	$0.075^{+0.073}_{-0.037}$	$3.903^{+1.824}_{-1.316}$
PDG	$\Lambda_b^0 \to \Lambda_c(2595)^+ \ell^- \bar{\nu}_\ell$	–		$7.9^{+4.0}_{-3.5}$	
LFQM	$\Lambda_b^0 \to \Lambda_c(2595)^+ e^- \bar{\nu}_e$	–		17.3 ± 5.9	
	$\Lambda_b^0 \to \Lambda_c(2595)^+ \mu^- \bar{\nu}_\mu$	–		17.2 ± 5.8	
	$\Lambda_b^0 \to \Lambda_c(2595)^+ \tau^- \bar{\nu}_\tau$	–		2.4 ± 1.1	
CCQM	$\Lambda_b^0 \to \Lambda_c(2595)^+ e^- \bar{\nu}_e$	–		8.6 ± 1.7	
	$\Lambda_b^0 \to \Lambda_c(2595)^+ \mu^- \bar{\nu}_\mu$	–		8.5 ± 1.7	
	$\Lambda_b^0 \to \Lambda_c(2595)^+ \tau^- \bar{\nu}_\tau$	–		1.1 ± 0.2	

- Lepton flavor universality ratio $\mathcal{R}(\Lambda_c^*) = \mathcal{B}r(\Lambda_b^0 \to \Lambda_c^* \tau^- \bar{\nu}_\tau)/\mathcal{B}r(\Lambda_b^0 \to \Lambda_c^* \mu^- \bar{\nu}_\mu)$:

For $\Lambda_b^0 \to \Lambda_c^+ \ell^- \bar{\nu}_\ell$:

References	Exp. [1]	[2]	[3]	[4]	[5,6]	[7]	[8]	[9]	[10]	[11]	[12]	$j^1_{\Lambda_c}$	$j^2_{\Lambda_c}$
$\mathcal{R}(\Lambda_c^+)$	0.242	0.31	0.28	0.333	0.324	0.313	0.294	0.29	0.33	0.317	0.332	0.274	0.239

For $\Lambda_b^0 \to \Lambda_c(2595)^+ \ell^- \bar{\nu}_\ell$:

This work		Type I	Type II	Type III	Type IV	Type V
$\mathcal{R}(\Lambda_c^*)$	$j^A_{\Lambda_c}$	$0.201^{+0.011}_{-0.011}$	$0.257^{+0.005}_{-0.003}$	$0.253^{+0.007}_{-0.005}$	$0.285^{+0.006}_{-0.005}$	$0.164^{+0.006}_{-0.004}$
	$j^P_{\Lambda_c}$	$0.188^{+0.016}_{-0.008}$	$0.189^{+0.001}_{-0.000}$	$0.193^{+0.001}_{-0.000}$	$0.193^{+0.001}_{-0.001}$	$0.182^{+0.006}_{-0.002}$
References	[13]		[14]		[15]	
$\mathcal{R}(\Lambda_c^*)$	0.14 ± 0.01		0.21, 0.22, 0.26, 0.31		0.13 ± 0.03	

[1] PRL, 128:191803, 2022.
[2] PRD, 97:074007, 2018.
[3] PRD, 99:054020, 2019.
[4] PRD, 92:034503, 2015.
[5] PRL, 121:202001, 2018.
[6] PRD, 99:055008, 2019.
[7] PRD, 94:073008, 2016.
[8] PRD, 91:074001, 2015.
[9] PRD, 91:115003, 2015.
[10] PRD, 100:113004, 2019.
[11] JHEP, 06:118, 2021.
[12] PRD, 102:094023, 2020.
[13] PRD, 104:013005, 2021.
[14] PRC, 72:035201, 2005.
[15] PRD, 98:053003, 2018.

Outline

Conclusions

- Form factors of $\Lambda_b \to \Lambda_c$ and $\Lambda_b \to \Lambda_c(2595)$ are calculated within QCD LCSRs.
- Both the positive parity and negative parity Λ_c and $\Lambda_c(2595)$ baryons are considered in the same LCSRs.
- Five different Λ_b baryon LCDAs models are used, and give us more insights on Λ_b LCDAs.
- Within the helicity form of semileptonic decay width, the branching ratios $\Lambda_b \to \Lambda_c \ell \bar{\nu}_\ell$ and $\Lambda_b \to \Lambda_c(2595) \ell \bar{\nu}_\ell$ are also given in our work, and also $\mathcal{R}(\Lambda_c^+)$ and $\mathcal{R}(\Lambda_c(2595)^+)$.
- In order to know more precise phenomenology results from LCSRs, more information of hadron interpolating currents and LCDAs should be investigate more thorough.

Thank you!