Semileptonic $s \to u$ decays of singly heavy baryons

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Introduction

Research Background and Significance

In heavy flavor physics, $s \to u$ weak decays of heavy flavor hadrons play a unique role:

The phase space is extremely small, and precise measurement of LFU is expected to be an important tool for testing the standard model.

The heavy quark symmetry can also be discussed, and it exhibits properties completely different from the case of heavy quark decays.

Experimental Progress

LHCb:

In 2015, it was discovered evidence of the $\Xi_b^- \to \Lambda_b^0 \pi^-$.

In 2023, $\mathcal{B}\left(\Xi_b^- \to \Lambda_b^0 \pi^-\right) = (0.89 \pm 0.10 \pm 0.07 \pm 0.29)\%$.

In 2020, $\mathcal{B}(\Xi_c^0 \to \Lambda_c^+ \pi^-) = (0.55 \pm 0.02 \pm 0.18)\%$.

In 2022, Belle revisited this decay channel [arXiv:2206.08527 [hep-ex]], confirming the previous measurement results of LHCb.

Method:

LFQM, within the three-quark picture: the three valence quarks in the baryon are treated independently.

Objective: $s \to u$ transitions

Categorized into four types based on the diquark species in the initial and final baryons (S-wave):

The $0^+ \to 0^+$ processes, $0^+ \to 1^+$ processes, $1^+ \to 0^+$ processes, $1^+ \to 1^+$ processes.

Framework and some applications

The baryon state

$$|\mathcal{B}(P,S,S_z)\rangle = \int \{d^3\tilde{p}_1\}\{d^3\tilde{p}_2\}\{d^3\tilde{p}_3\}2(2\pi)^3\delta^3(\tilde{P}-\tilde{p}_1-\tilde{p}_2-\tilde{p}_3)\frac{1}{\sqrt{P^+}}$$

$$\times \sum_{\lambda_1,\lambda_2,\lambda_3} \Psi^{SS_z}(\tilde{p}_1,\tilde{p}_2,\tilde{p}_3,\lambda_1,\lambda_2,\lambda_3)C^{ijk}|q_1^i(p_1,\lambda_1)q_2^j(p_2,\lambda_2)q_3^k(p_3,\lambda_3)\rangle$$

spin and momentum color flavor

$$\left(\frac{1}{2}\otimes\frac{1}{2}\right)\otimes\frac{1}{2} = (0\oplus 1)\otimes\frac{1}{2} = \frac{1}{2}\oplus\frac{1}{2}\oplus\frac{3}{2}$$

$\Lambda_Q(diquark: 0^+)$ $A_0\bar{u}(p_3,\lambda_3)(\bar{P}\cdot\gamma + M_0)(-\gamma_5)C\bar{u}^T(p_2,\lambda_2)\bar{u}(p_1,\lambda_1)u(\bar{P},S_z)\Phi(\mathrm{x_i},\mathrm{k_{i\perp}})$

$\Sigma_Q(diquark: 1^+)$ $\mathrm{A}_1\bar{u}(p_3,\lambda_3)(\bar{P}\cdot\gamma + M_0)(\gamma^\mu - v^\mu)C\bar{u}^T(p_2,\lambda_2)\bar{u}(p_1,\lambda_1)(\frac{1}{\sqrt{3}}\gamma_\mu\gamma_5)u(\bar{P},S_z)\Phi(\mathrm{x_i},\mathrm{k_{i\perp}})$

Z. X. Zhao. [arXiv:2304.07698 [hep-ph]]

Transition form factors

The form factors for four types of processes： $\Xi_Q \to \Lambda_Q/\Sigma_Q, \Omega_Q \to \Xi_Q^{(\prime)}$.

overlap factor:

$$\Xi_c^+(csu) \to \Sigma_c^{++}(cuu) \qquad 1/\sqrt{2} \times 2$$

$1/\sqrt{2}$:normalization of flavor wave function. 2: the contraction of two equivalent quarks.

$\Xi_Q \to \Lambda_Q$ Form factors:

1.Calculate the matrix elements in LFQM

2.Write the matrix elements in terms of form factors:

$$\langle \Lambda_Q(P',S_z')|\bar{u}\gamma^\mu s|\Xi_Q(P,S)\rangle = \bar{u}(P',S_z')\left[\gamma^\mu f_1(q^2) + i\sigma^{\mu\nu}\frac{q_\nu}{M}f_2(q^2) + \frac{q^\mu}{M}f_3(q^2)\right]u(P,S_z)$$

$$\langle \Lambda_Q(P',S_z')|\bar{u}\gamma^\mu\gamma_5 s|\Xi_Q(P,S)\rangle = \bar{u}(P',S_z')\left[\gamma^\mu g_1(q^2) + i\sigma^{\mu\nu}\frac{q_\nu}{M}g_2(q^2) + \frac{q^\mu}{M}g_3(q^2)\right]\gamma_5 u(P,S_z)$$

Transition form factors

3. Extract the form factors

Choose the $q^+ = 0$ coordinate system and extract $f_i, g_i (i = 1,2)$:

multiply $\sum_{S_z S_z'} \bar{u}(P, S_z)\gamma^+ u(P', S_z')$ by the "+" component of the LFQM and the parametrization formula respectively:

$$f_1 = \frac{1}{8P^+P'^+}\int \{d^3\tilde{p}_2\}\{d^3\tilde{p}_3\}\frac{A_0' A_0}{\sqrt{p_1'^+ p_1^+ P'^+ P^+}}\Phi'^*\Phi\, Tr[(\bar{P}\cdot\gamma + M_0)\Gamma_2\,(\bar{P}'\cdot\gamma + M_0')(p_2\cdot\gamma + m_2)]$$

$$\times Tr[(\bar{P}\cdot\gamma + M_0)\gamma_5 C(p_3\cdot\gamma + m_3)^T C(-\gamma_5)(\bar{P}'\cdot\gamma + M_0')(p_1'\cdot\gamma + m_1')\Gamma_1\,(p_1\cdot\gamma + m_1)]$$

$$\Gamma_1 = \gamma^+, \Gamma_2 = \gamma^+.$$

f_2, g_1, g_2 can also be obtained in a similar way

Transition form factors

The extraction of f_3 and g_3, select the "⊥" components of the transformation matrix:

$\sum_{S_z S_z'} \bar{u}(P, S_z)\gamma^+ u(P', S_z')$ multiply the $j-th$ ($j = 1$or 2) component of parameterization formula

$$f_1 - f_3\left(1 + \frac{M'}{M}\right) = \frac{1}{4P^+q^2}\int\{d\tilde{p}_2\}\{d\tilde{p}_3\}\frac{A_0' A_0}{\sqrt{p_1'^+ p_1^+ P'^+ P^+}}\Phi'^*\Phi \times \sum_{j=1}^{2} q^j$$

$$\{Tr\left[(\bar{P}\cdot\gamma + M_0)\gamma_5 C(p_3\cdot\gamma + m_3)^T C(-\gamma_5)(\bar{P}'\cdot\gamma + M_0')(p_1'\cdot\gamma + m_1')\gamma^j(p_1\cdot\gamma + m_1)\right]$$

$$\times Tr[(\bar{P}\cdot\gamma + M_0)\gamma^+(\bar{P}'\cdot\gamma + M_0')\,(p_2\cdot\gamma + m_2)]\}\Big|_{P^j=0}.$$

$$g_1 + g_3\left(1 - \frac{M'}{M}\right) = \frac{1}{4P^+q^2}\int\{d\tilde{p}_2\}\{d\tilde{p}_3\}\frac{A_0' A_0}{\sqrt{p_1'^+ p_1^+ P'^+ P^+}}\Phi'^*\Phi \times \sum_{j=1}^{2} q^j$$

$$\{Tr\left[(\bar{P}\cdot\gamma + M_0)\gamma_5 C(p_3\cdot\gamma + m_3)^T C(-\gamma_5)(\bar{P}'\cdot\gamma + M_0')(p_1'\cdot\gamma + m_1')\gamma^j\gamma_5(p_1\cdot\gamma + m_1)\right]$$

$$\times Tr[(\bar{P}\cdot\gamma + M_0)\gamma^+\gamma_5(\bar{P}'\cdot\gamma + M_0')\,(p_2\cdot\gamma + m_2)]\}\Big|_{P^j=0}.$$

The heavy quark limit

Form factors at $q^2 = 0$ in the heavy quark limit:

	$f_1(0)$	$f_2(0)$	$f_3(0)$	$g_1(0)$	$g_2(0)$	$g_3(0)$
$0^+ \to 0^+$	1	$\frac{1}{2}$	$\frac{1}{2}\frac{1}{x_1}\boxed{\frac{(k_{1\perp}+k'_{1\perp})\cdot q_\perp}{q_\perp^2}}$	0	0	0
$0^+ \to 1^+$	0	$\frac{1}{\sqrt{3}}\frac{1}{x_1}$	0	$-\frac{1}{\sqrt{3}}$	$-\frac{1}{\sqrt{3}}(\frac{1}{2}+\frac{1}{x_1}\boxed{\frac{(k_{1\perp}+k'_{1\perp})\cdot q_\perp}{q_\perp^2}})$	$\frac{1}{\sqrt{3}}\frac{M}{M-M'}\frac{1}{x_1}\boxed{\frac{(k_{1\perp}+k'_{1\perp})\cdot q_\perp}{q_\perp^2}}$
$1^+ \to 0^+$	0	$\frac{1}{\sqrt{3}}\frac{1}{x_1}$	0	$-\frac{1}{\sqrt{3}}$	$-\frac{1}{\sqrt{3}}(-\frac{1}{2}+\frac{1}{x_1}\boxed{\frac{(k_{1\perp}+k'_{1\perp})\cdot q_\perp}{q_\perp^2}})$	$\frac{1}{\sqrt{3}}\frac{M}{M-M'}\frac{1}{x_1}\boxed{\frac{(k_{1\perp}+k'_{1\perp})\cdot q_\perp}{q_\perp^2}}$
$1^+ \to 1^+$	1	$-\frac{2}{3}\frac{1}{x_1}$	$\frac{1}{2}\frac{1}{x_1}\boxed{\frac{(k_{1\perp}+k'_{1\perp})\cdot q_\perp}{q_\perp^2}}$	$\frac{2}{3}$	$\frac{2}{3}\frac{1}{x_1}\boxed{\frac{(k_{1\perp}+k'_{1\perp})\cdot q_\perp}{q_\perp^2}}$	$-\frac{2}{3}\frac{M}{M-M'}\frac{1}{x_1}\boxed{\frac{(k_{1\perp}+k'_{1\perp})\cdot q_\perp}{q_\perp^2}}$

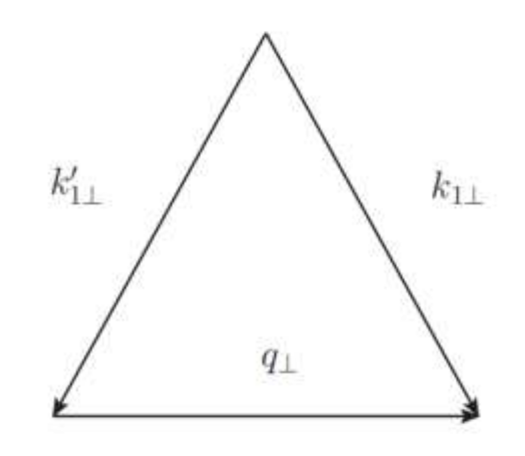
Attention: $(k_{1\perp} + k'_{1\perp}) \cdot q_\perp$

the initial s quark and the final u quark are on an equal footing

$|k_{1\perp}| = |k'_{1\perp}|$

$k'_{1\perp} \cdot q_\perp = -k_{1\perp} \cdot q_\perp$

$(k_{1\perp} + k'_{1\perp}) \cdot q_\perp = 0$



Numerical results

Inputs

Inputs $m_u = m_d = 0.25$ GeV, $m_s = 0.37$ GeV, $m_c = 1.4$ GeV, $m_b = 4.8$ GeV.

The uncertainty introduced by the quark mass, considering the scope (in units of GeV):

$$m_u = m_d = 0.22\sim0.28,\ m_s = 0.37\sim0.5,\ m_c = 1.3\sim1.81,\ m_b = 4.7\sim5.2.$$

Masses (in units of MeV) of initial and final baryons

Transition	M_i	M_f	$M_i - M_f$
$\Xi_c^0 \to \Lambda_c^+$	2470.44 ± 0.28	2286.46 ± 0.14	183.98 ± 0.42
$\Xi_b^- \to \Lambda_b^0$	5797.0 ± 0.6	5619.6 ± 0.17	177.4 ± 0.77
$\Xi_c^+ \to \Sigma_c^{++}$	2467.71 ± 0.23	2453.97 ± 0.14	13.74 ± 0.37
$\Xi_c^0 \to \Sigma_c^+$	2470.44 ± 0.28	$2452.65^{+0.22}_{-0.16}$	$17.79^{+0.44}_{-0.50}$
$\Omega_c^0 \to \Xi_c^+$	2695.2 ± 1.7	2467.71 ± 0.23	227.49 ± 1.93
$\Omega_b^- \to \Xi_b^0$	6045.8 ± 0.8	5791.9 ± 0.5	253.9 ± 1.3
$\Omega_c^0 \to \Xi_c^{\prime +}$	2695.2 ± 1.7	2578.2 ± 0.5	117.0 ± 2.2
$\Omega_b^- \to \Xi_b^{\prime 0}$	6045.8 ± 0.8	5935.1 ± 0.5	110.7 ± 1.3

$m_e = 0.511$ MeV,

$m_\mu = 106$ MeV.

Shape parameters

shape parameters (in units of GeV)

$$\beta_{b[ud]} = 0.66, \qquad \beta_{c[ud]} = 0.56, \qquad \beta_{[ud]} = 0.32,$$
$$\beta_{b[sq]} = 0.68, \qquad \beta_{c[sq]} = 0.58, \qquad \beta_{[sq]} = 0.39,$$
$$\beta_{b\{qq\}} = 0.68, \qquad \beta_{c\{qq\}} = 0.58, \qquad \beta_{\{qq\}} = 0.39,$$
$$\beta_{b\{sq\}} = 0.73, \qquad \beta_{c\{sq\}} = 0.63, \qquad \beta_{\{sq\}} = 0.42,$$
$$\beta_{b\{ss\}} = 0.78, \qquad \beta_{c\{ss\}} = 0.66, \qquad \beta_{\{ss\}} = 0.44.$$

For the shape parameters of diquarks, we adopt these approximations:

$$\beta_{[ud]} = \beta_{u\bar{d}}, \quad \beta_{[sq]} = \beta_{s\bar{u}}, \quad \beta_{\{ss\}} = \beta_{s\bar{s}}.$$

H. Y. Cheng. [arXiv:hep-ph/0310359 [hep-ph]].

It is expected that there exists approximately 10% uncertainty in these shape parameters for baryons.

Form factors and uncertainties

form factors at $q^2 = 0$

Transition	$f_1(0)$	$f_2(0)$	$f_3(0)$	$g_1(0)$	$g_2(0)$	$g_3(0)$
$\Xi_c^0 \to \Lambda_c^+$	0.963 ± 0.001	0.419 ± 0.002	-0.179 ± 0.807	0.000 ± 0.000	0.001 ± 0.000	-0.025 ± 0.001
$\Xi_b^- \to \Lambda_b^0$	0.961 ± 0.001	0.447 ± 0.001	-0.625 ± 2.943	0.000 ± 0.000	0.000 ± 0.000	-0.027 ± 0.001
$\Xi_c^0 \to \Sigma_c^+$	-0.000 ± 0.000	1.311 ± 0.027	-0.020 ± 0.000	-0.345 ± 0.000	0.146 ± 0.254	50.692 ± 75.260
$\Omega_c^0 \to \Xi_c^+$	-0.000 ± 0.000	1.921 ± 0.041	-0.027 ± 0.000	-0.463 ± 0.000	0.012 ± 0.392	3.342 ± 10.751
$\Omega_b^- \to \Xi_b^0$	-0.000 ± 0.000	4.242 ± 0.128	-0.027 ± 0.000	-0.444 ± 0.001	0.072 ± 1.349	13.070 ± 80.887
$\Omega_c^0 \to \Xi_c^{\prime +}$	1.396 ± 0.001	-1.599 ± 0.045	-0.533 ± 1.468	0.531 ± 0.000	-0.131 ± 0.471	-11.406 ± 26.584
$\Omega_b^- \to \Xi_b^{\prime 0}$	1.392 ± 0.002	-4.219 ± 0.156	-1.374 ± 4.838	0.511 ± 0.001	-0.337 ± 1.605	-68.078 ± 219.844

The actual calculation results are consistent with the predictions from the heavy-quark limit.

	$f_1(0)$	$f_2(0)$	$f_3(0)$	$g_1(0)$	$g_2(0)$	$g_3(0)$
$0^+ \to 0^+$	1	$\frac{1}{2}$	$\frac{1}{2}\frac{1}{x_1}\frac{(k_{1\perp}+k'_{1\perp})\cdot q_\perp}{q_\perp^2}$	0	0	0
$0^+ \to 1^+$	0	$\frac{1}{\sqrt{3}}\frac{1}{x_1}$	0	$-\frac{1}{\sqrt{3}}$	$-\frac{1}{\sqrt{3}}\left(\frac{1}{2}+\frac{1}{x_1}\frac{(k_{1\perp}+k'_{1\perp})\cdot q_\perp}{q_\perp^2}\right)$	$\frac{1}{\sqrt{3}}\frac{M}{M-M'}\frac{1}{x_1}\frac{(k_{1\perp}+k'_{1\perp})\cdot q_\perp}{q_\perp^2}$
$1^+ \to 0^+$	0	$\frac{1}{\sqrt{3}}\frac{1}{x_1}$	0	$-\frac{1}{\sqrt{3}}$	$-\frac{1}{\sqrt{3}}\left(-\frac{1}{2}+\frac{1}{x_1}\frac{(k_{1\perp}+k'_{1\perp})\cdot q_\perp}{q_\perp^2}\right)$	$\frac{1}{\sqrt{3}}\frac{M}{M-M'}\frac{1}{x_1}\frac{(k_{1\perp}+k'_{1\perp})\cdot q_\perp}{q_\perp^2}$
$1^+ \to 1^+$	1	$-\frac{2}{3}\frac{1}{x_1}$	$\frac{1}{2}\frac{1}{x_1}\frac{(k_{1\perp}+k'_{1\perp})\cdot q_\perp}{q_\perp^2}$	$\frac{2}{3}$	$\frac{2}{3}\frac{1}{x_1}\frac{(k_{1\perp}+k'_{1\perp})\cdot q_\perp}{q_\perp^2}$	$-\frac{2}{3}\frac{M}{M-M'}\frac{1}{x_1}\frac{(k_{1\perp}+k'_{1\perp})\cdot q_\perp}{q_\perp^2}$

Fitting of form factors

The form factors f_i and g_i are calculated in the spacelike region of q^2. To extrapolate to the physical region of q^2, we adopt the following fit formula:

$$F(q^2) = \frac{a + b\, z(q^2)}{1 - \frac{q^2}{\left(m_{pole}^{f}\right)^2}},$$

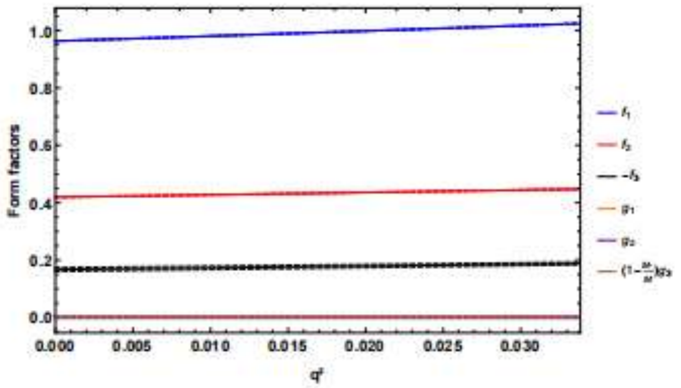
Where

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

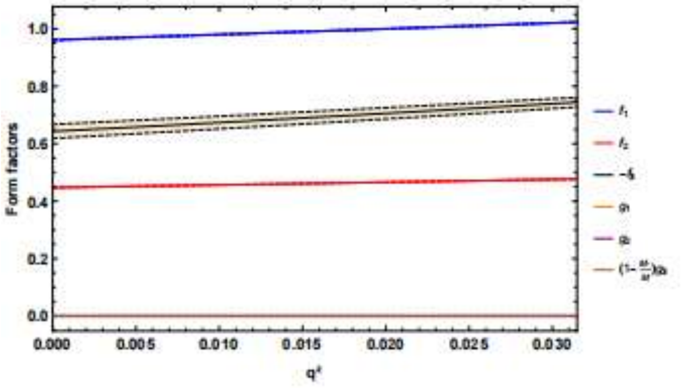
with $t_+ = (m_K + m_\pi)^2$ and $t_0 = q^2_{max} = (M - M')^2$. The pole masses m_{pole}^{f} are respectively taken as $m_{pole}^{f_1,f_2} = m_{K^*}$, $m_{pole}^{f_3} = m_{K^*(700)}$, $m_{pole}^{g_1,g_2} = m_{K_1(1270)}$,$m_{pole}^{g_3} = m_K$.

Fitting of form factors

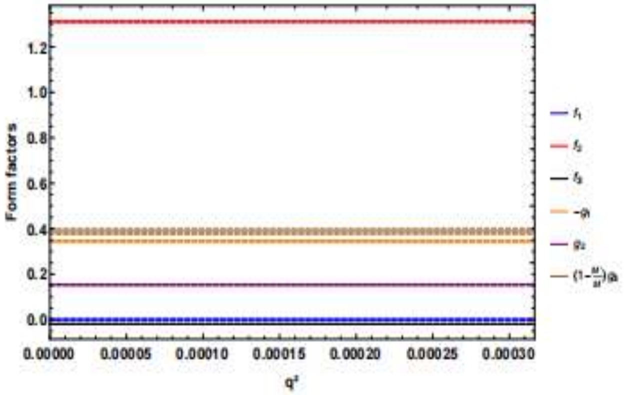
The dependence of our form factors on q^2, where g_3 have been rescaled by a small factor $1-\frac{M'}{M}$ with $M(')$ the mass of the initial (final) baryon.



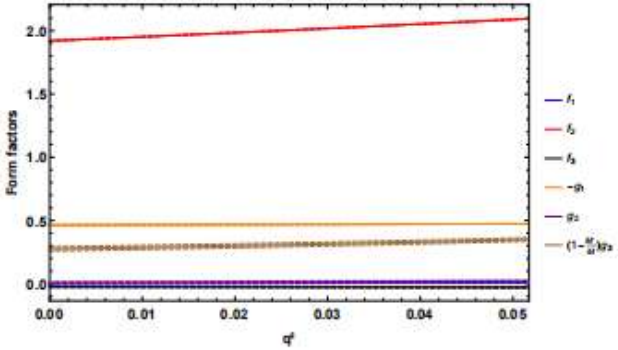
(a) $\Xi_c^0 \to \Lambda_c^+$



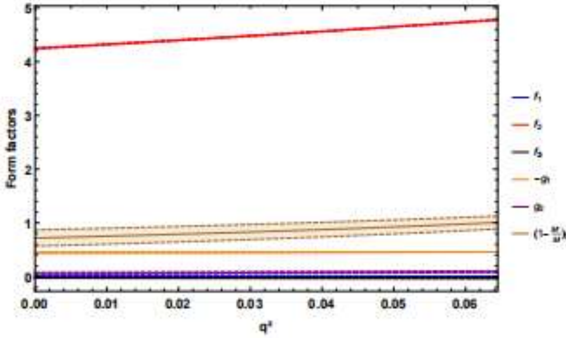
(b) $\Xi_b^- \to \Lambda_b^0$



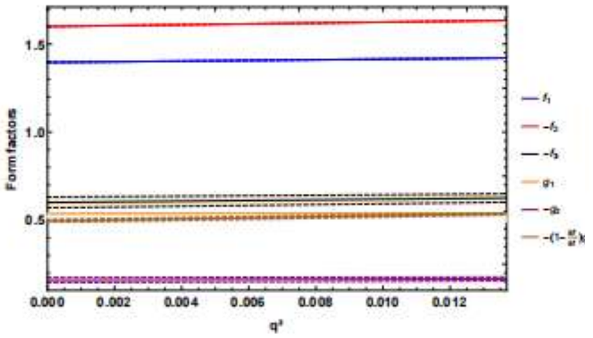
(c) $\Xi_c^0 \to \Sigma_c^+$



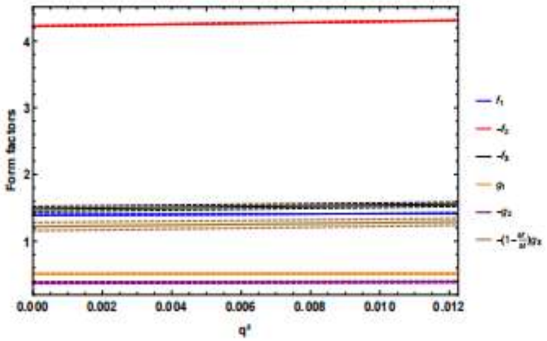
(d) $\Omega_c^0 \to \Xi_c^+$



(e) $\Omega_b^- \to \Xi_b^0$



(f) $\Omega_c^0 \to \Xi_c'^+$



(g) $\Omega_b^- \to \Xi_b'^0$

Fitting of form factors

Transition	(a,b) of f_1	(a,b) of f_2	(a,b) of f_3
$\Xi_c^0 \to \Lambda_c^+$	$(0.981 \pm 0.000, -0.798 \pm 0.004)$	$(0.428 \pm 0.000, -0.409 \pm 0.004)$	$(-0.185 \pm 0.006, 0.696 \pm 0.154)$
$\Xi_b^- \to \Lambda_b^0$	$(0.983 \pm 0.000, -1.065 \pm 0.012)$	$(0.458 \pm 0.000, -0.529 \pm 0.003)$	$(-0.711 \pm 0.016, 3.363 \pm 0.409)$
$\Xi_c^0 \to \Sigma_c^+$	$(-0.000 \pm 0.000, -0.153 \pm 0.001)$	$(1.311 \pm 0.000, -0.935 \pm 0.015)$	$(-0.019 \pm 0.000, 0.085 \pm 0.001)$
$\Omega_c^0 \to \Xi_c^+$	$(0.007 \pm 0.000, -0.196 \pm 0.001)$	$(1.959 \pm 0.000, -1.107 \pm 0.007)$	$(-0.028 \pm 0.000, 0.032 \pm 0.001)$
$\Omega_b^- \to \Xi_b^0$	$(0.004 \pm 0.000, -0.091 \pm 0.000)$	$(4.392 \pm 0.005, -3.356 \pm 0.090)$	$(-0.030 \pm 0.000, 0.052 \pm 0.002)$
$\Omega_c^0 \to \Xi_c'^+$	$(1.397 \pm 0.000, -0.090 \pm 0.004)$	$(-1.606 \pm 0.000, 0.707 \pm 0.009)$	$(-0.613 \pm 0.024, 1.493 \pm 0.852)$
$\Omega_b^- \to \Xi_b'^0$	$(1.396 \pm 0.000, -0.552 \pm 0.005)$	$(-4.243 \pm 0.005, 2.534 \pm 0.184)$	$(-1.526 \pm 0.031, 5.789 \pm 1.131)$
Transition	(a,b) of g_1	(a,b) of g_2	(a,b) of g_3
$\Xi_c^0 \to \Lambda_c^+$	$(-0.000 \pm 0.000, 0.006 \pm 0.000)$	$(0.001 \pm 0.000, -0.001 \pm 0.000)$	$(-0.022 \pm 0.000, -0.111 \pm 0.003)$
$\Xi_b^- \to \Lambda_b^0$	$(-0.000 \pm 0.000, 0.001 \pm 0.000)$	$(0.000 \pm 0.000, -0.001 \pm 0.000)$	$(-0.025 \pm 0.000, -0.090 \pm 0.009)$
$\Xi_c^0 \to \Sigma_c^+$	$(-0.345 \pm 0.000, -0.064 \pm 0.002)$	$(0.153 \pm 0.002, -0.292 \pm 0.100)$	$(53.789 \pm 1.480, -155.769 \pm 75.860)$
$\Omega_c^0 \to \Xi_c^+$	$(-0.458 \pm 0.000, -0.154 \pm 0.001)$	$(0.021 \pm 0.003, -0.240 \pm 0.051)$	$(3.263 \pm 0.119, -0.270 \pm 2.270)$
$\Omega_b^- \to \Xi_b^0$	$(-0.439 \pm 0.000, -0.124 \pm 0.006)$	$(0.088 \pm 0.013, -0.747 \pm 0.214)$	$(17.615 \pm 2.105, -12.249 \pm 33.873)$
$\Omega_c^0 \to \Xi_c'^+$	$(0.529 \pm 0.000, 0.248 \pm 0.002)$	$(-0.165 \pm 0.011, 0.634 \pm 0.409)$	$(-11.547 \pm 0.129, 6.284 \pm 4.643)$
$\Omega_b^- \to \Xi_b'^0$	$(0.509 \pm 0.000, 0.198 \pm 0.018)$	$(-0.389 \pm 0.012, 1.373 \pm 0.427)$	$(-66.914 \pm 2.722, 48.731 \pm 100.281)$

The error is very small because $\langle \mathcal{B}_f(v', s') | \bar{u}\gamma_\mu(1-\gamma_5)s | \mathcal{B}_i(v, s)\rangle$ is similar to $\langle \mathcal{B}(v', s') | \mathcal{B}(v, s)\rangle$.

Semileptonic decay prediction

Channel	$\Gamma/$ GeV	$\mathcal{B}$	Γ_L/Γ_T	$P_L/$ GeV
$\Xi_c^0 \to \Lambda_c^+ e^- \bar{\nu}_e$	$(6.68 \pm 0.00 \pm 0.08) \times 10^{-19}$	$(1.53 \pm 0.00 \pm 0.02) \times 10^{-7}$	$(4.46 \pm 0.02 \pm 0.05) \times 10^{4}$	$(6.02 \pm 0.12 \pm 0.29) \times 10^{-5}$
$\Xi_b^- \to \Lambda_b^0 e^- \bar{\nu}_e$	$(5.94 \pm 0.01 \pm 0.14) \times 10^{-19}$	$(1.42 \pm 0.00 \pm 0.03) \times 10^{-6}$	$(1.04 \pm 0.01 \pm 0.03) \times 10^{6}$	$(9.65 \pm 0.04 \pm 0.47) \times 10^{-6}$
$\Xi_c^+ \to \Sigma_c^{++} e^- \bar{\nu}_e$	$(1.27 \pm 0.00 \pm 0.18) \times 10^{-24}$	$(0.87 \pm 0.00 \pm 0.12) \times 10^{-12}$	$1.25 \pm 0.00 \pm 0.00$	$(-1.18 \pm 0.00 \pm 0.03) \times 10^{-2}$
$\Xi_c^0 \to \Sigma_c^+ e^- \bar{\nu}_e$	$(2.31 \pm 0.00 \pm 0.31) \times 10^{-24}$	$(5.27 \pm 0.00 \pm 0.70) \times 10^{-13}$	$1.25 \pm 0.00 \pm 0.00$	$(-1.53 \pm 0.00 \pm 0.05) \times 10^{-2}$
$\Omega_c^0 \to \Xi_c^+ e^- \bar{\nu}_e$	$(1.33 \pm 0.00 \pm 0.06) \times 10^{-18}$	$(5.50 \pm 0.00 \pm 0.24) \times 10^{-7}$	$1.18 \pm 0.00 \pm 0.00$	$-0.20 \pm 0.00 \pm 0.00$
$\Omega_b^- \to \Xi_b^0 e^- \bar{\nu}_e$	$(2.29 \pm 0.01 \pm 0.07) \times 10^{-18}$	$(5.70 \pm 0.01 \pm 0.17) \times 10^{-6}$	$1.16 \pm 0.00 \pm 0.00$	$-0.23 \pm 0.00 \pm 0.00$
$\Omega_c^0 \to \Xi_c^{\prime +} e^- \bar{\nu}_e$	$(2.13 \pm 0.00 \pm 0.21) \times 10^{-19}$	$(8.86 \pm 0.00 \pm 0.86) \times 10^{-8}$	$6.51 \pm 0.01 \pm 0.02$	$-0.69 \pm 0.00 \pm 0.00$
$\Omega_b^- \to \Xi_b^{\prime 0} e^- \bar{\nu}_e$	$(1.64 \pm 0.00 \pm 0.10) \times 10^{-19}$	$(4.08 \pm 0.00 \pm 0.25) \times 10^{-7}$	$6.93 \pm 0.01 \pm 0.02$	$-0.68 \pm 0.00 \pm 0.00$
$\Xi_c^0 \to \Lambda_c^+ \mu^- \bar{\nu}_\mu$	$(1.28 \pm 0.00 \pm 0.03) \times 10^{-19}$	$(2.93 \pm 0.00 \pm 0.06) \times 10^{-8}$	$(6.17 \pm 0.02 \pm 0.08) \times 10^{4}$	$(8.52 \pm 0.08 \pm 0.20) \times 10^{-5}$
$\Xi_b^- \to \Lambda_b^0 \mu^- \bar{\nu}_\mu$	$(0.98 \pm 0.00 \pm 0.04) \times 10^{-19}$	$(2.34 \pm 0.00 \pm 0.10) \times 10^{-7}$	$(1.48 \pm 0.02 \pm 0.05) \times 10^{6}$	$(1.39 \pm 0.01 \pm 0.04) \times 10^{-5}$
$\Omega_c^0 \to \Xi_c^+ \mu^- \bar{\nu}_\mu$	$(4.63 \pm 0.00 \pm 0.30) \times 10^{-19}$	$(1.92 \pm 0.00 \pm 0.12) \times 10^{-7}$	$0.90 \pm 0.00 \pm 0.00$	$-0.20 \pm 0.00 \pm 0.00$
$\Omega_b^- \to \Xi_b^0 \mu^- \bar{\nu}_\mu$	$(0.99 \pm 0.00 \pm 0.04) \times 10^{-18}$	$(2.48 \pm 0.01 \pm 0.10) \times 10^{-6}$	$0.93 \pm 0.00 \pm 0.00$	$-0.23 \pm 0.00 \pm 0.00$
$\Omega_c^0 \to \Xi_c^{\prime +} \mu^- \bar{\nu}_\mu$	$(3.13 \pm 0.00 \pm 2.85) \times 10^{-22}$	$(1.30 \pm 0.00 \pm 1.18) \times 10^{-10}$	$4.22 \pm 0.01 \pm 0.05$	$-0.27 \pm 0.00 \pm 0.02$
$\Omega_b^- \to \Xi_b^{\prime 0} \mu^- \bar{\nu}_\mu$	$(1.57 \pm 0.00 \pm 2.15) \times 10^{-23}$	$(3.92 \pm 0.00 \pm 5.36) \times 10^{-11}$	$4.38 \pm 0.01 \pm 0.04$	$-0.18 \pm 0.00 \pm 0.02$

In the heavy quark limit, $\Gamma = \frac{G_F^2 |V_{CKM}|^2 (M-M')^5}{60\pi^3} (f_1^2 + 3g_1^2)$.

Two semi-muonic decays are not allowed.

Lepton flavor universality prediction

$$\frac{\Gamma(\Xi_c^0 \to \Lambda_c^+ \mu^- \bar{\upsilon}_\mu)}{\Gamma(\Xi_c^0 \to \Lambda_c^+ e^- \bar{\upsilon}_e)} = 0.19 \pm 0.00 \pm 0.00, \frac{\Gamma(\Xi_b^- \to \Lambda_b^0 \mu^- \bar{\upsilon}_\mu)}{\Gamma(\Xi_b^- \to \Lambda_b^0 e^- \bar{\upsilon}_e)} = 0.16 \pm 0.00 \pm 0.00.$$

$$\frac{\Gamma(\Omega_c^0 \to \Xi_c^+ \mu^- \bar{\upsilon}_\mu)}{\Gamma(\Omega_c^0 \to \Xi_c^+ e^- \bar{\upsilon}_e)} = 0.35 \pm 0.00 \pm 0.01, \frac{\Gamma(\Omega_b^- \to \Xi_b^0 \mu^- \bar{\upsilon}_\mu)}{\Gamma(\Omega_b^- \to \Xi_b^0 e^- \bar{\upsilon}_e)} = 0.43 \pm 0.00 \pm 0.01.$$

$$\frac{\Gamma(\Omega_c^0 \to \Xi_c'^+ \mu^- \bar{\upsilon}_\mu)}{\Gamma(\Omega_c^0 \to \Xi_c'^+ e^- \bar{\upsilon}_e)} = (1.47 \pm 0.00 \pm 1.09) \times 10^{-3},$$

$$\frac{\Gamma(\Omega_b^- \to \Xi_b'^0 \mu^- \bar{\upsilon}_\mu)}{\Gamma(\Omega_b^- \to \Xi_b'^0 e^- \bar{\upsilon}_e)} = (0.96 \pm 0.00 \pm 1.18) \times 10^{-4}.$$

where the first and second uncertainties are respectively from those of the form factors and the masses of initial and final baryons.

The decay width of the semi-μ channel is much smaller than that of the semi-e channel, which is due to the extremely limited phase space.

Semileptonic decay comparison

Channel	This work	Ref. [5]	Ref. [6]	Ref. [9]
$\Xi_c^0 \to \Lambda_c^+ e^- \bar{\nu}_e$	$(6.68 \pm 0.00 \pm 0.08) \times 10^{-19}$	7.91×10^{-19}	- -	7.839×10^{-19}
$\Xi_b^- \to \Lambda_b^0 e^- \bar{\nu}_e$	$(5.94 \pm 0.01 \pm 0.14) \times 10^{-19}$	6.16×10^{-19}	- -	5.928×10^{-19}
$\Xi_c^+ \to \Sigma_c^{++} e^- \bar{\nu}_e$	$(1.27 \pm 0.00 \pm 0.18) \times 10^{-24}$	3.74×10^{-24}	- -	- -
$\Xi_c^0 \to \Sigma_c^+ e^- \bar{\nu}_e$	$(2.31 \pm 0.00 \pm 0.31) \times 10^{-24}$	6.97×10^{-24}	- -	7.023×10^{-24}
$\Omega_c^0 \to \Xi_c^+ e^- \bar{\nu}_e$	$(1.33 \pm 0.00 \pm 0.06) \times 10^{-18}$	2.26×10^{-18}	9.05×10^{-18}	2.290×10^{-18}
$\Omega_b^- \to \Xi_b^0 e^- \bar{\nu}_e$	$(2.29 \pm 0.01 \pm 0.07) \times 10^{-18}$	4.05×10^{-18}	- -	4.007×10^{-18}
$\Omega_c^0 \to \Xi_c'^+ e^- \bar{\nu}_e$	$(2.13 \pm 0.00 \pm 0.21) \times 10^{-19}$	3.63×10^{-19}	3.65×10^{-19}	- -
$\Omega_b^- \to \Xi_b'^0 e^- \bar{\nu}_e$	$(1.64 \pm 0.00 \pm 0.10) \times 10^{-19}$	- -	- -	- -
$\Xi_c^0 \to \Lambda_c^+ \mu^- \bar{\nu}_\mu$	$(1.28 \pm 0.00 \pm 0.03) \times 10^{-19}$	1.3×10^{-19}	- -	- -
$\Xi_b^- \to \Lambda_b^0 \mu^- \bar{\nu}_\mu$	$(0.98 \pm 0.00 \pm 0.04) \times 10^{-19}$	0.91×10^{-19}	- -	- -
$\Omega_c^0 \to \Xi_c^+ \mu^- \bar{\nu}_\mu$	$(4.63 \pm 0.00 \pm 0.30) \times 10^{-19}$	7.1×10^{-19}	- -	- -
$\Omega_b^- \to \Xi_b^0 \mu^- \bar{\nu}_\mu$	$(0.99 \pm 0.00 \pm 0.04) \times 10^{-18}$	1.7×10^{-18}	- -	- -
$\Omega_c^0 \to \Xi_c'^+ \mu^- \bar{\nu}_\mu$	$(3.13 \pm 0.00 \pm 2.85) \times 10^{-22}$	10×10^{-22}	- -	- -
$\Omega_b^- \to \Xi_b'^0 \mu^- \bar{\nu}_\mu$	$(1.57 \pm 0.00 \pm 2.15) \times 10^{-23}$	- -	- -	- -

Ref.[5]:S. Faller and T. Mannel, [arXiv:1503.06088 [hep-ph]].
Ref.[6]:N. Soni and J. Pandya, Nucl. Phys. 60, 694-695 (2015).
Ref.[9]:Z. Shah, Nucl. Phys. 66, 891-892 (2023).

Summary and outlook

Summary and outlook

- Calculated the form factors involving f_3 and g_3, taking into account the results in the heavy quark limit.
- Predicted semi-leptonic decay and made a comparison.
- Precise measurement of LFU for these processes is expected to be an important tool for testing the standard model.

THANK YOU