Axial-vector transition form factors of light and singly heavy baryons in χQSM

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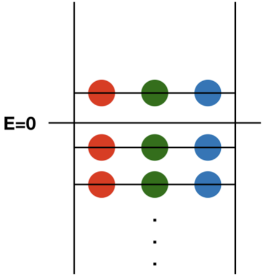
Motivation

- Understanding the axial-vector transition form factors is important because it provides significant information for describing the neutrino-nucleon scattering.
- One of axial-vector transitions, hyperon semi-leptonic decay gives the constraint of Cabibbo-Kobayashi-Maskawa mixing angles.

The effective partition function

$$Z_{\chi QSM} = \mathcal{N} \int D\psi D\psi^\dagger DU^a exp\Big[- \int d^4 x \psi^\dagger i\Big(i\partial\!\!\!/ + iMU^{\gamma_5} + i\hat{m}\Big)\psi\Big]$$

A baryon in the large N_c limit
E.Witten Nucl. Phys. B 160(1979) 57
A baryon can be described as a state of N_c
quarks bound by mesonic mean-field.



Baryon correlation function

$$\Pi_N(T) = \langle 0|J_N(0, T/2)J_N^\dagger(0, -T/2)|0\rangle \sim e^{-N_c E_{\mathrm{val}} + E_{\mathrm{sea}}}$$

Introduction of rotational zero modes

$$\frac{\delta S}{\delta U_a} = 0$$

In the large N_c limit, we can get the classical mesonic configuration by solving the saddle-point equation.

We consider the rotational and translational zero modes to construct the nucleon states.

$$DU(\vec{x})F(U(x)) \Rightarrow \int d^3zDAF(AU_c(\vec{x}-\vec{z})A^\dagger)$$

Collective Hamiltonian

$$
\begin{aligned}
H_{\mathrm{coll}} &= H_s + H_{sb} \\
H_s &= M_c + \frac{1}{2I_1} J_i J_i + \frac{1}{2I_2} J_a J_a + \frac{M_1}{\bar{m}} \Sigma_{SU(2)} \\
H_{sb} &= \alpha D^{(8)}_{88} + \beta Y + \frac{\gamma}{\sqrt{3}} D^{(8)}_{8i} J_i
\end{aligned}
$$

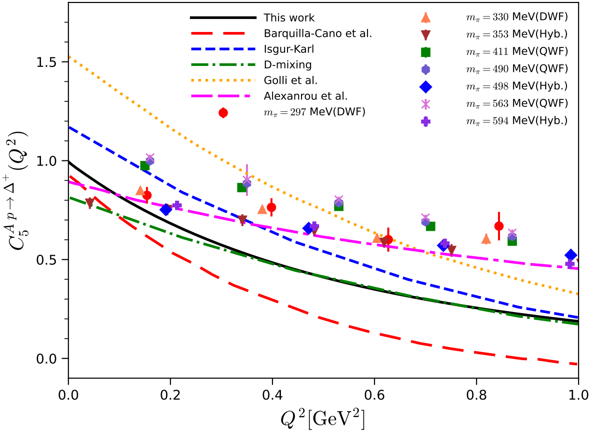
$$
\alpha = \frac{1}{\bar{m}} \frac{1}{\sqrt{3}} M_8 \Sigma_{SU(2)} - \frac{N_c}{\sqrt{3}} M_8 \frac{K_2}{I_2} \quad \beta = \sqrt{3} M_8 \frac{K_2}{I_2} \quad \gamma = -2\sqrt{3} M_8 \left(\frac{K_1}{I_1} - \frac{K_2}{I_2} \right) .
$$

Decomposition of axial-vector transition FF

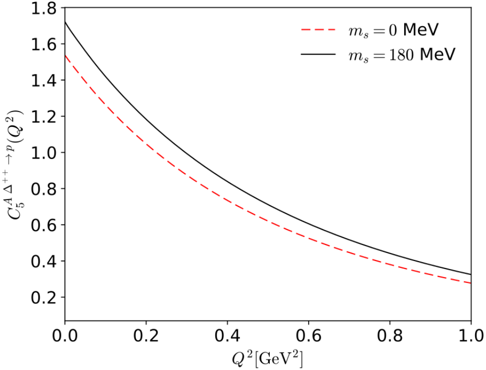
$$\begin{aligned}
&\langle B^{(8)}(p_f, s_f)|A^{\mu(3)}|B^{(10)}(p_i, s_i)\rangle \\
&= \bar{u}(p_f)\left[\frac{C_3^A(q^2)}{M_8}(\not{q}g^{\mu\nu} - \gamma^\mu q^\nu) + \frac{C_4^A(q^2)}{M_8^2}(p_f^\lambda q_\lambda g^{\mu\nu} - q^\nu p_f^\mu)\right. \\
&\left. + C_5^A(q^2)g^{\mu\nu} + \frac{C_6^A(q^2)}{M_8^2}q^\mu q^\nu\right] u_\nu(p_i),
\end{aligned}$$

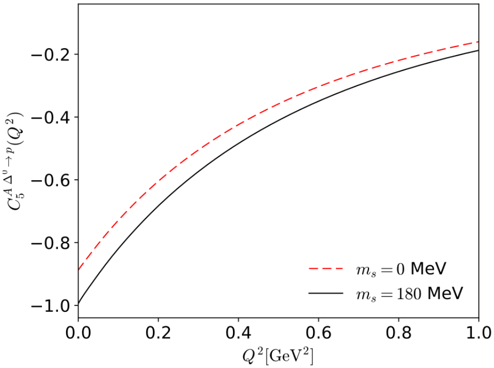
$C_5^A(q^2)$ is the most important form factor because it can directly be related to the $g_{\pi N\Delta}$ coupling.

Axial-vector transition form factor of $\Delta^+ \to p$

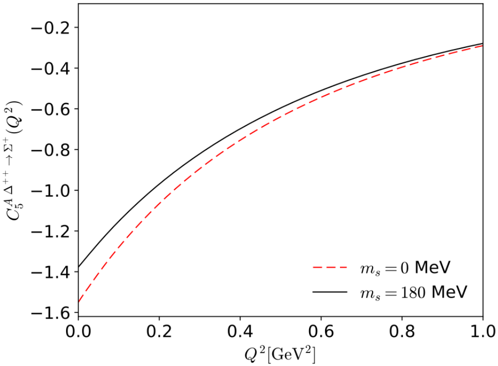


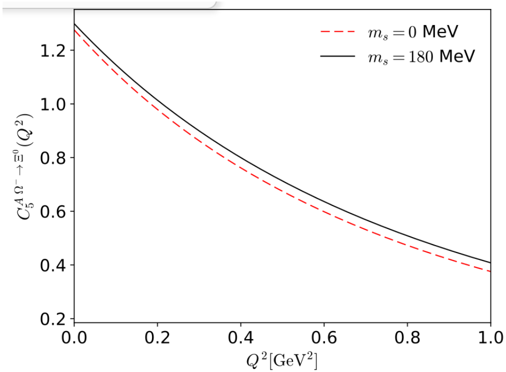
Strangeness conserving axial-vector transition FF



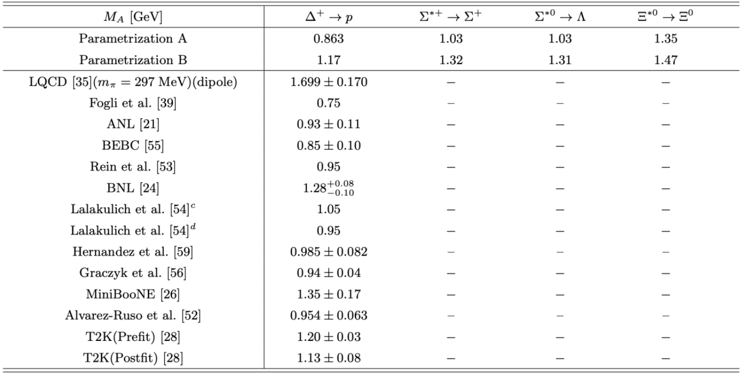


Strangeness changing axial-vector transition FF





Axial mass



M_A [GeV]	$\Delta^+ \to p$	$\Sigma^{*+} \to \Sigma^+$	$\Sigma^{*0} \to \Lambda$	$\Xi^{*0} \to \Xi^0$
Parametrization A	0.863	1.03	1.03	1.35
Parametrization B	1.17	1.32	1.31	1.47
LQCD [35]($m_\pi = 297$ MeV)(dipole)	1.699 ± 0.170	–	–	–
Fogli et al. [39]	0.75	–	–	–
ANL [21]	0.93 ± 0.11	–	–	–
BEBC [55]	0.85 ± 0.10	–	–	–
Rein et al. [53]	0.95	–	–	–
BNL [24]	$1.28^{+0.08}_{-0.10}$	–	–	–
Lalakulich et al. [54]^c	1.05	–	–	–
Lalakulich et al. [54]^d	0.95	–	–	–
Hernandez et al. [59]	0.985 ± 0.082	–	–	–
Graczyk et al. [56]	0.94 ± 0.04	–	–	–
MiniBooNE [26]	1.35 ± 0.17	–	–	–
Alvarez-Ruso et al. [52]	0.954 ± 0.063	–	–	–
T2K(Prefit) [28]	1.20 ± 0.03	–	–	–
T2K(Postfit) [28]	1.13 ± 0.08	–	–	–

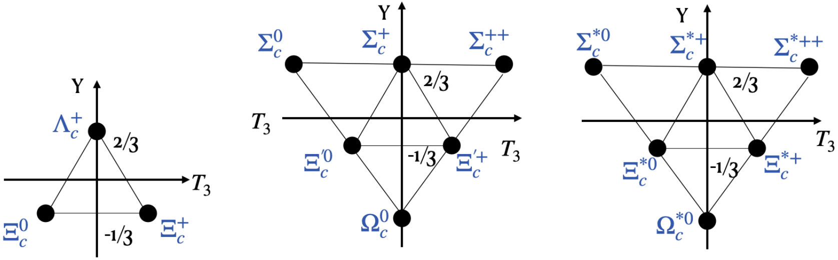
$$C_5^A(Q^2) = \frac{C_5^A(0)}{(1 + Q^2/M_A^2)^2}$$

$$C_5^A(Q^2) = \frac{C_5^A(0)(1 + aQ^2/(b + Q^2))}{(1 + Q^2/M_A^2)^2}$$

$$a = -1.2, \quad b = 2.0$$

Axial-vector transition FF of singly heavy baryon

In the heavy quark mass limit, a heavy quark spin is conserved so the spin of light-quark system is conserved.



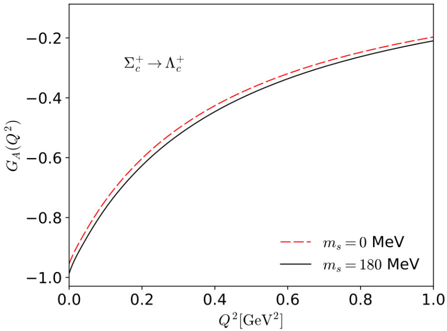
Decomposition of axial-vector transition FF

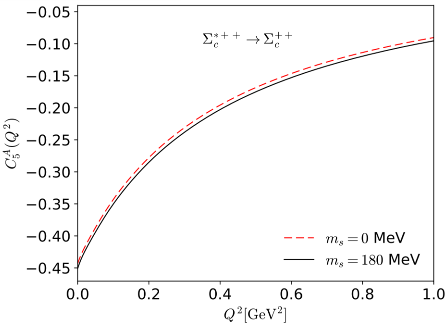
$$A_\mu^a(x) = \bar{\psi}(x)\gamma_\mu\gamma_5\frac{\lambda^a}{2}\psi(x) + \bar{\Psi}(x)\gamma_\mu\gamma_5\Psi(x),$$

$$\langle B'_{1/2}(p_f, J_3')|A_\mu^a(0)|B_{1/2}(p_i, J_3)\rangle = \bar{u}(p_f, J_3')\left[G_A^{(a)}(q^2)\gamma_\mu + \frac{G_P^{(a)}(q^2)}{M'+M}q_\mu\right]\frac{\gamma_5}{2}u(p_i, J_3)$$

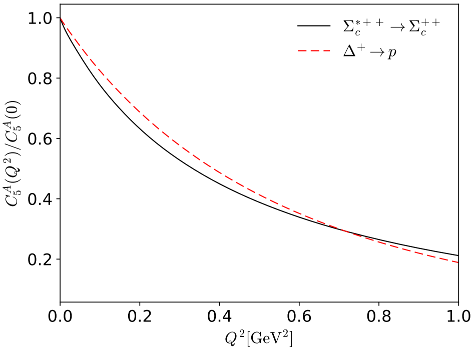
$$\begin{aligned}
&\langle B'_{\frac{1}{2}}(p', J_3')|A_\mu^a(0)|B_{\frac{3}{2}}(p, J_3)\rangle \\
&= \overline{u}(p', J_3')\left[\left\{\frac{C_3^{A(a)}(q^2)}{M'}\gamma^\nu + \frac{C_4^{A(a)}(q^2)}{M'^2}p^\nu\right\}(g_{\alpha\mu}g_{\rho\nu} - g_{\alpha\rho}g_{\mu\nu})q^\rho\right. \\
&\qquad\left. + C_5^{A(a)}(q^2)g_{\alpha\mu} + \frac{C_6^{A(a)}(q^2)}{M'^2}q_\alpha q_\mu\right]u^\alpha(p, J_3).
\end{aligned}$$

Axial-vector transition FF of singly heavy baryon





Decomposition of axial-vector transition FF



Comparison axial-vector transition FF between light baryon and singly heavy baryon

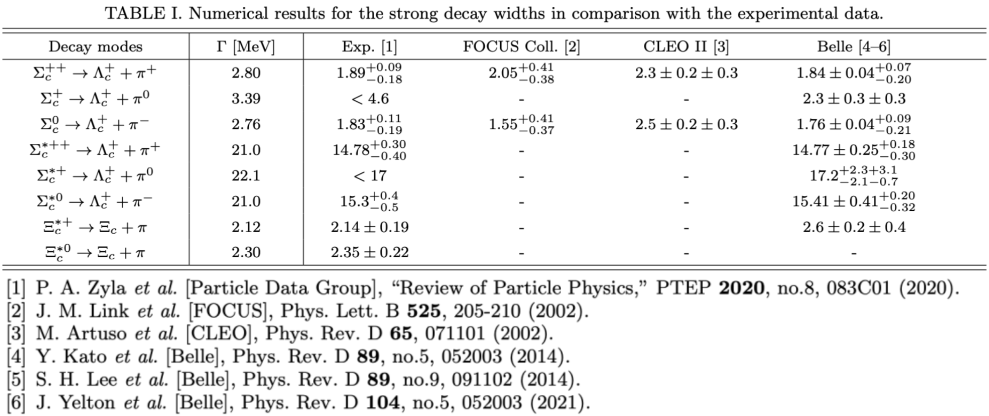


TABLE I. Numerical results for the strong decay widths in comparison with the experimental data.

Decay modes	Γ [MeV]	Exp. [1]	FOCUS Coll. [2]	CLEO II [3]	Belle [4–6]
$\Sigma_c^{++} \to \Lambda_c^+ + \pi^+$	2.80	$1.89^{+0.09}_{-0.18}$	$2.05^{+0.41}_{-0.38}$	$2.3 \pm 0.2 \pm 0.3$	$1.84 \pm 0.04^{+0.07}_{-0.20}$
$\Sigma_c^{+} \to \Lambda_c^+ + \pi^0$	3.39	< 4.6	-	-	$2.3 \pm 0.3 \pm 0.3$
$\Sigma_c^{0} \to \Lambda_c^+ + \pi^-$	2.76	$1.83^{+0.11}_{-0.19}$	$1.55^{+0.41}_{-0.37}$	$2.5 \pm 0.2 \pm 0.3$	$1.76 \pm 0.04^{+0.09}_{-0.21}$
$\Sigma_c^{*++} \to \Lambda_c^+ + \pi^+$	21.0	$14.78^{+0.30}_{-0.40}$	-	-	$14.77 \pm 0.25^{+0.18}_{-0.30}$
$\Sigma_c^{*+} \to \Lambda_c^+ + \pi^0$	22.1	< 17	-	-	$17.2^{+2.3+3.1}_{-2.1-0.7}$
$\Sigma_c^{*0} \to \Lambda_c^+ + \pi^-$	21.0	$15.3^{+0.4}_{-0.5}$	-	-	$15.41 \pm 0.41^{+0.20}_{-0.32}$
$\Xi_c^{*+} \to \Xi_c + \pi$	2.12	2.14 ± 0.19	-	-	$2.6 \pm 0.2 \pm 0.4$
$\Xi_c^{*0} \to \Xi_c + \pi$	2.30	2.35 ± 0.22	-	-	-

[1] P. A. Zyla *et al.* [Particle Data Group], "Review of Particle Physics," PTEP **2020**, no.8, 083C01 (2020).
[2] J. M. Link *et al.* [FOCUS], Phys. Lett. B **525**, 205-210 (2002).
[3] M. Artuso *et al.* [CLEO], Phys. Rev. D **65**, 071101 (2002).
[4] Y. Kato *et al.* [Belle], Phys. Rev. D **89**, no.5, 052003 (2014).
[5] S. H. Lee *et al.* [Belle], Phys. Rev. D **89**, no.9, 091102 (2014).
[6] J. Yelton *et al.* [Belle], Phys. Rev. D **104**, no.5, 052003 (2021).

Summary

- We calculated the axial-vector transition form factors of light and singly heavy baryons within the chiral quark-soliton model.
- The decay widths of singly heavy baryons are computed and are compared with the experimental data.

Thank you very much!