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

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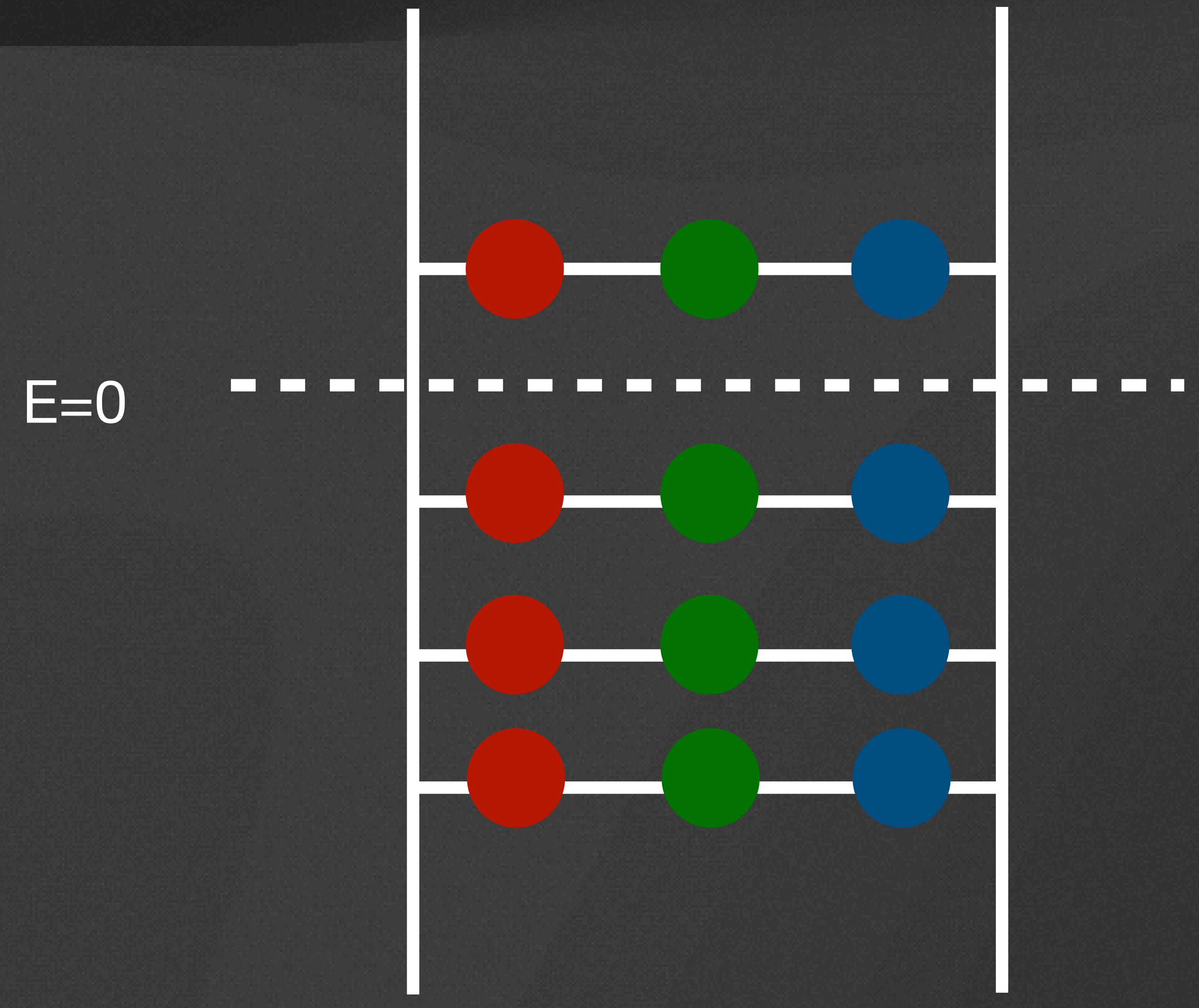
Motivation

- Understanding the axial-vector transition form factor 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

$$Z_{\chi\mathrm{QSM}} = N_c \int D\psi D\psi^\dagger DU^a \left[-\int d^4x \psi^\dagger i(i\partial\!\!\!/ + iMU^{\gamma^5} + i\hat{m})\psi \right]$$

$$U^{\gamma_5} = \frac{1+\gamma_5}{2}U + \frac{1-\gamma_5}{2}U^\dagger$$



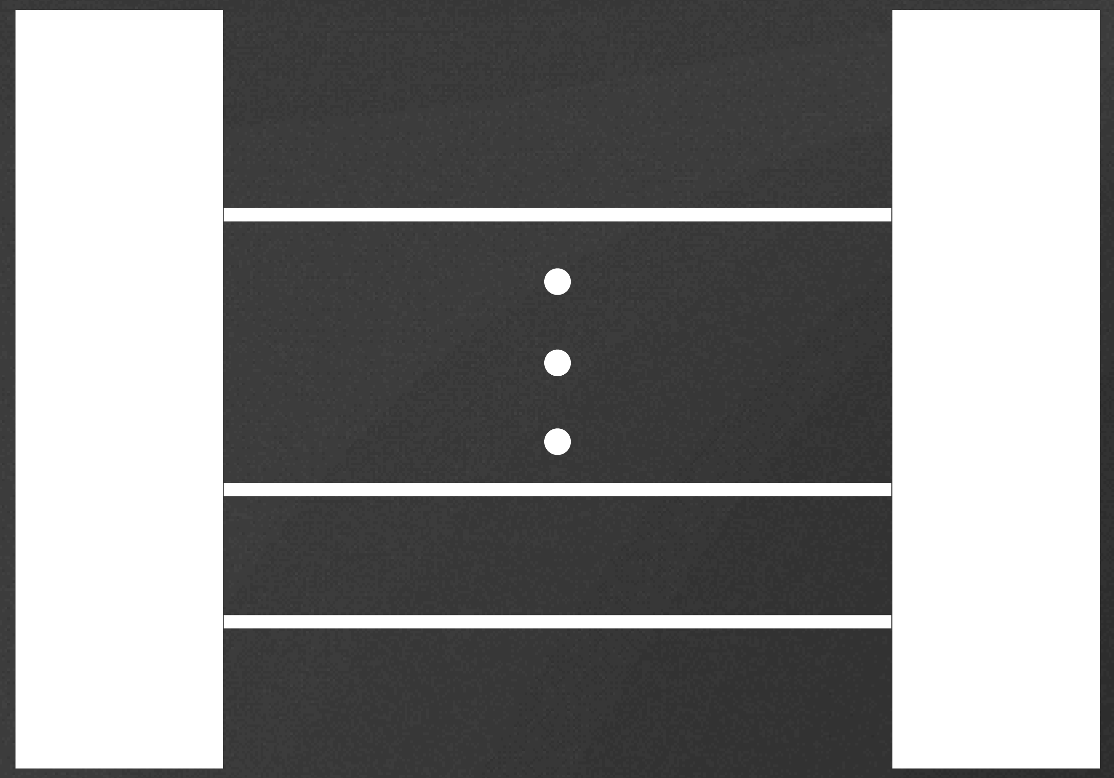
A baryon in the large Nc limit

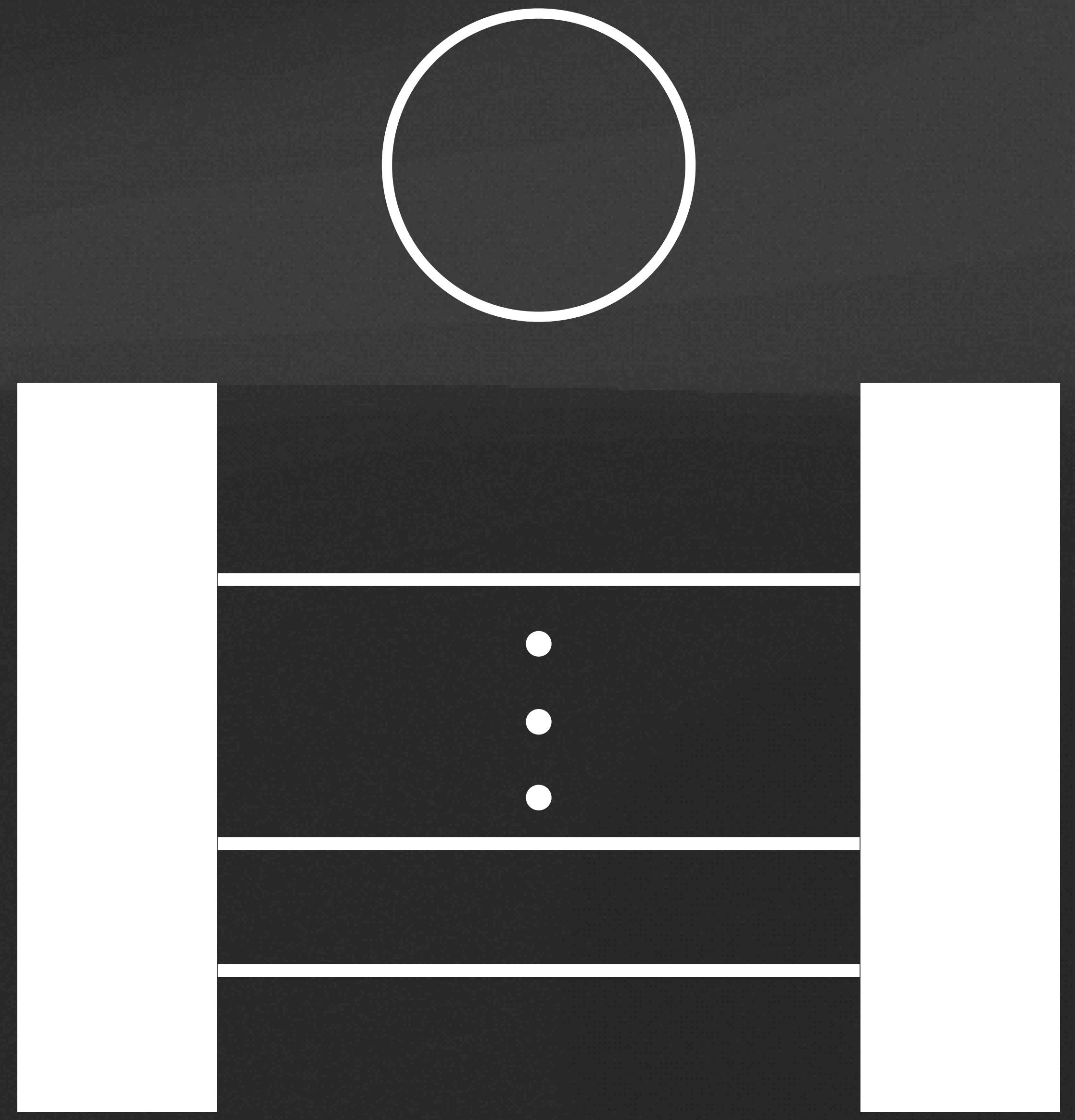
E.Witten Nucl. Phys. B 160 (1979) 57

A baryon can be described as a state of
Nc quarks bound by mesonic mean-field.

Baryon correlation function

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





Vacuum Polarization

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.

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

A(t) : SU(3) matrices

Collective Hamiltonian

$$H_{\text{coll}} = H_s + H_{sb}$$

$$H_s = M_c + \frac{1}{2I_1} J_i J_i + \frac{1}{2I_2} J_a J_a + \frac{M_1}{\bar{m}} \Sigma_{SU(2)}$$

$$H_{sb} = \alpha D^{(8)}_{88} + \beta Y + \frac{\gamma}{\sqrt{3}} D^{(8)}_{8i} J_i$$

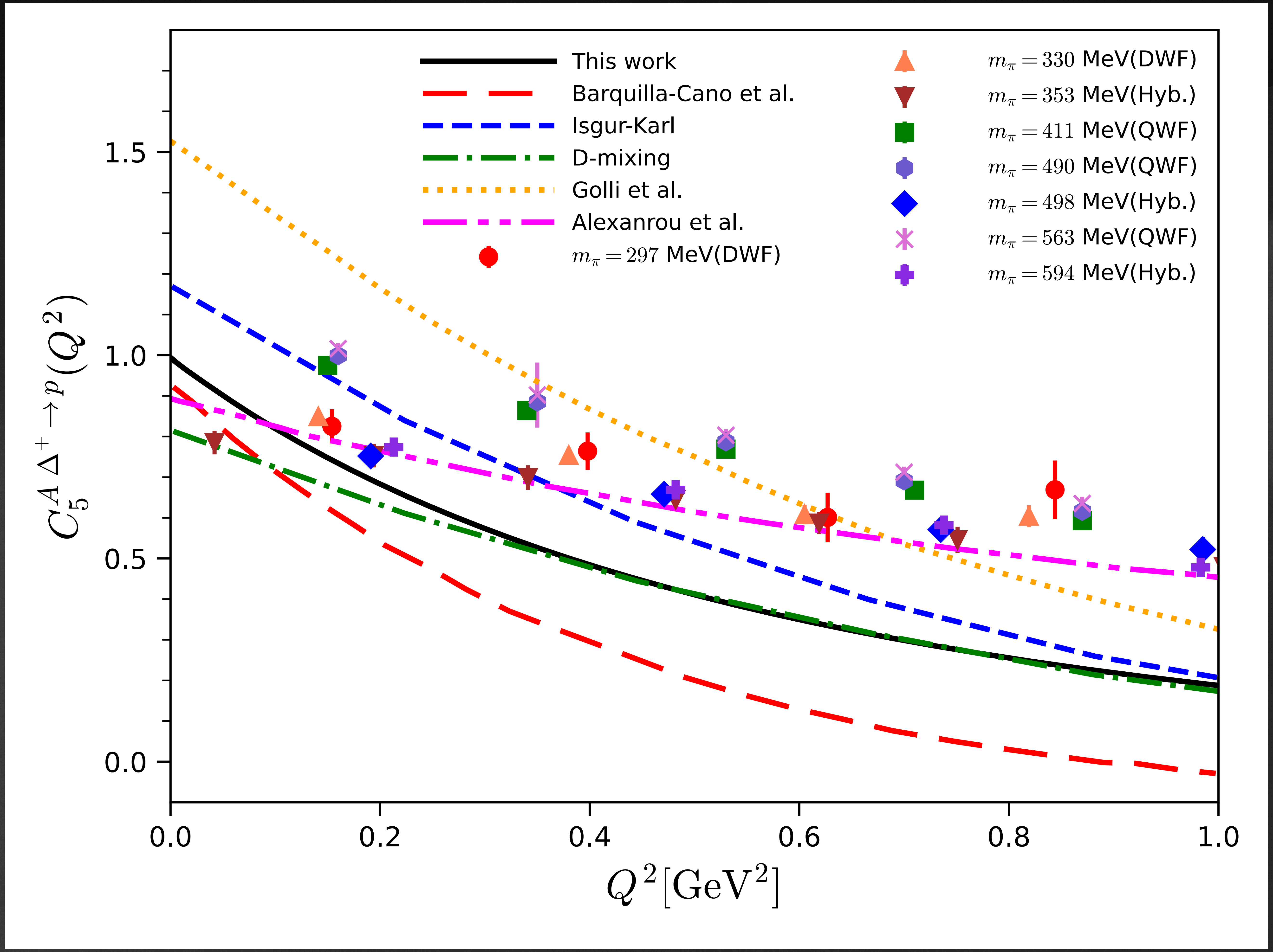
$$\alpha = \frac{1}{\bar{m}} \frac{1}{\sqrt{3}} M_8 \Sigma_{SU(2)} - \frac{N_c}{\sqrt{3}} M_8 \frac{K_2}{I_2} \quad \beta = \sqrt{3} M_8 \frac{K_2}{I_2} \quad \gamma = -2\sqrt{3} M_8 \left(\frac{K_1}{I_1} - \frac{K_2}{I_2} \right)$$

Decomposition of axial-vector transition FF

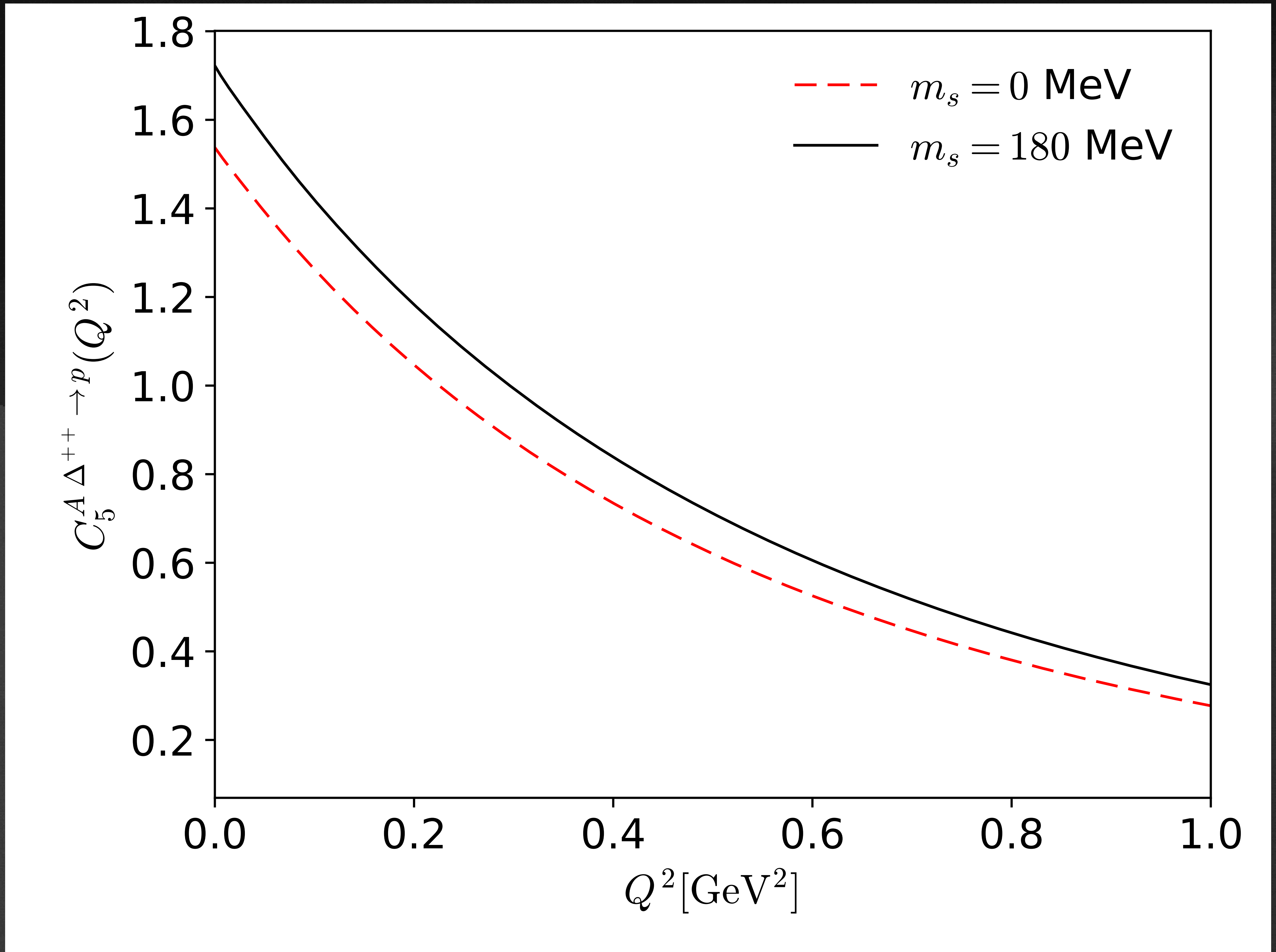
$$
\begin{aligned}
&\langle B^{(8)}(p_f, s_f)|A^{\mu(3)}|B^{(10)}(p_i, s_i)\rangle \\
&= \bar{u}(p_f)\left[\frac{C_3^A(q^2)}{M_8}(\not{q}g^{\mu\nu} - \gamma^\mu q^\nu) + \frac{C_4^A(q^2)}{M_8^2}(p_f^\lambda q_\lambda g^{\mu\nu} - q^\nu p_f^\mu)\right. \\
&\left. +C_5^A(q^2)g^{\mu\nu} + \frac{C_6^A(q^2)}{M_8^2}q^\mu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

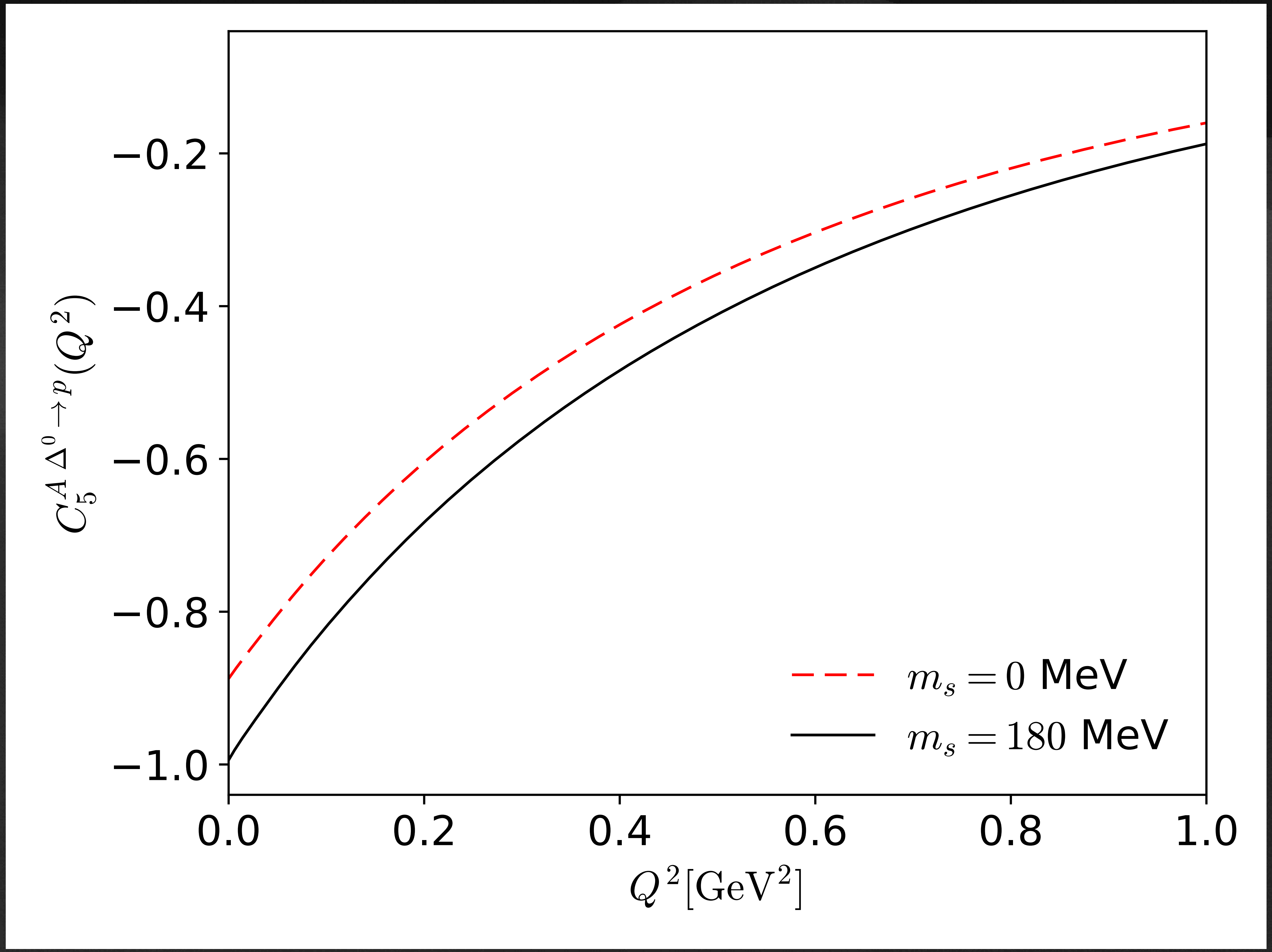
- $C_5^A(q^2)$ is the most important form factor because it can directly be related to the $g_{\pi N\Delta}$ coupling.

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

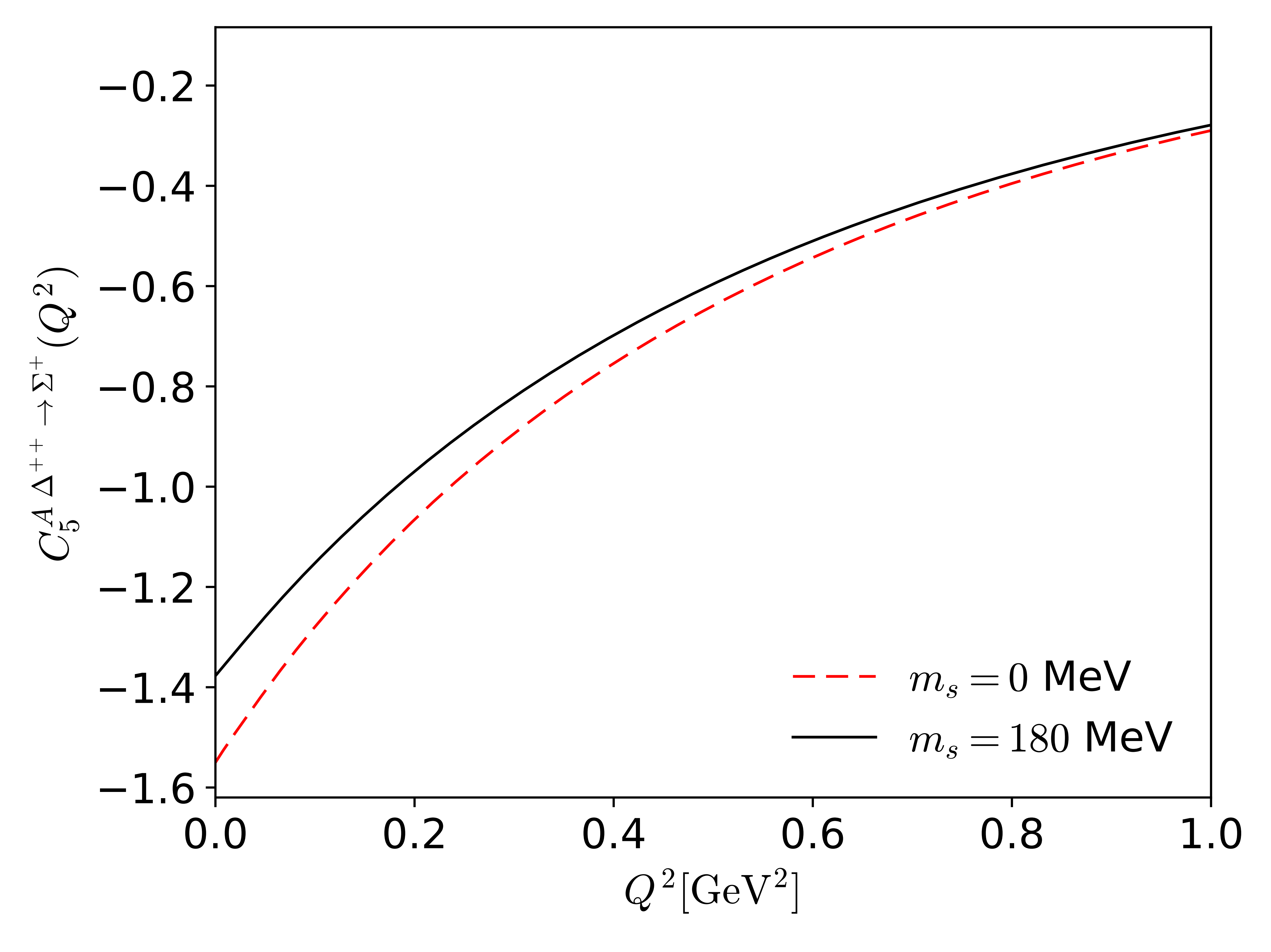


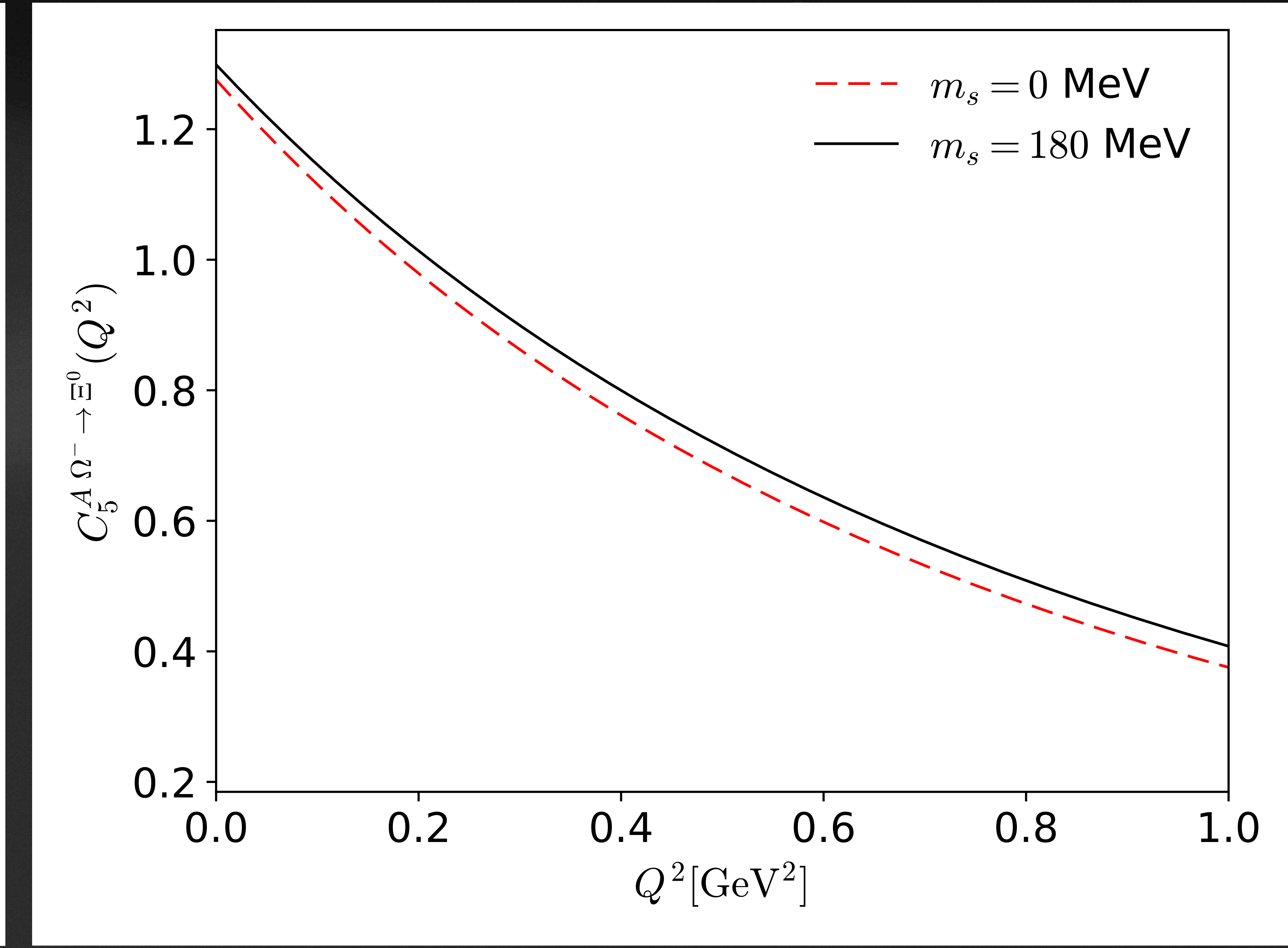
Strangeness conserving axial-vector transition FF





Strangeness changing axial-vector transition FF





Axial mass

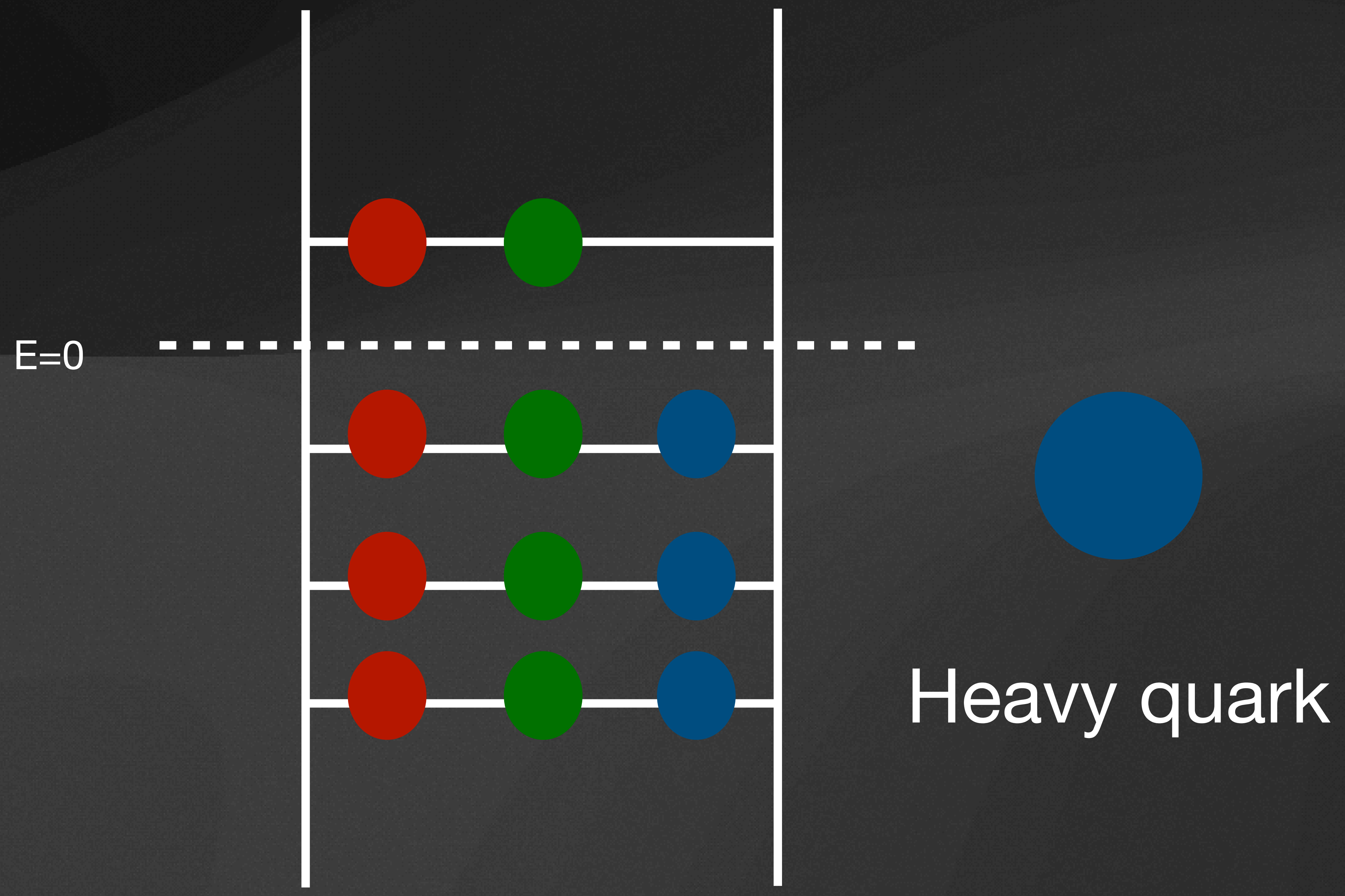
M_A [GeV]	$\Delta^+ \to p$	$\Sigma^{*+} \to \Sigma^+$	$\Sigma^{*0} \to \Lambda$	$\Xi^{*0} \to \Xi^0$
Parametrization A	0.863	1.03	1.03	1.35
Parametrization B	1.17	1.32	1.31	1.47
LQCD [35]($m_\pi = 297$ MeV)(dipole)	1.699 ± 0.170	–	–	–
Fogli et al. [39]	0.75	–	–	–
ANL [21]	0.93 ± 0.11	–	–	–
BEBC [55]	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	–	–	–

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

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

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

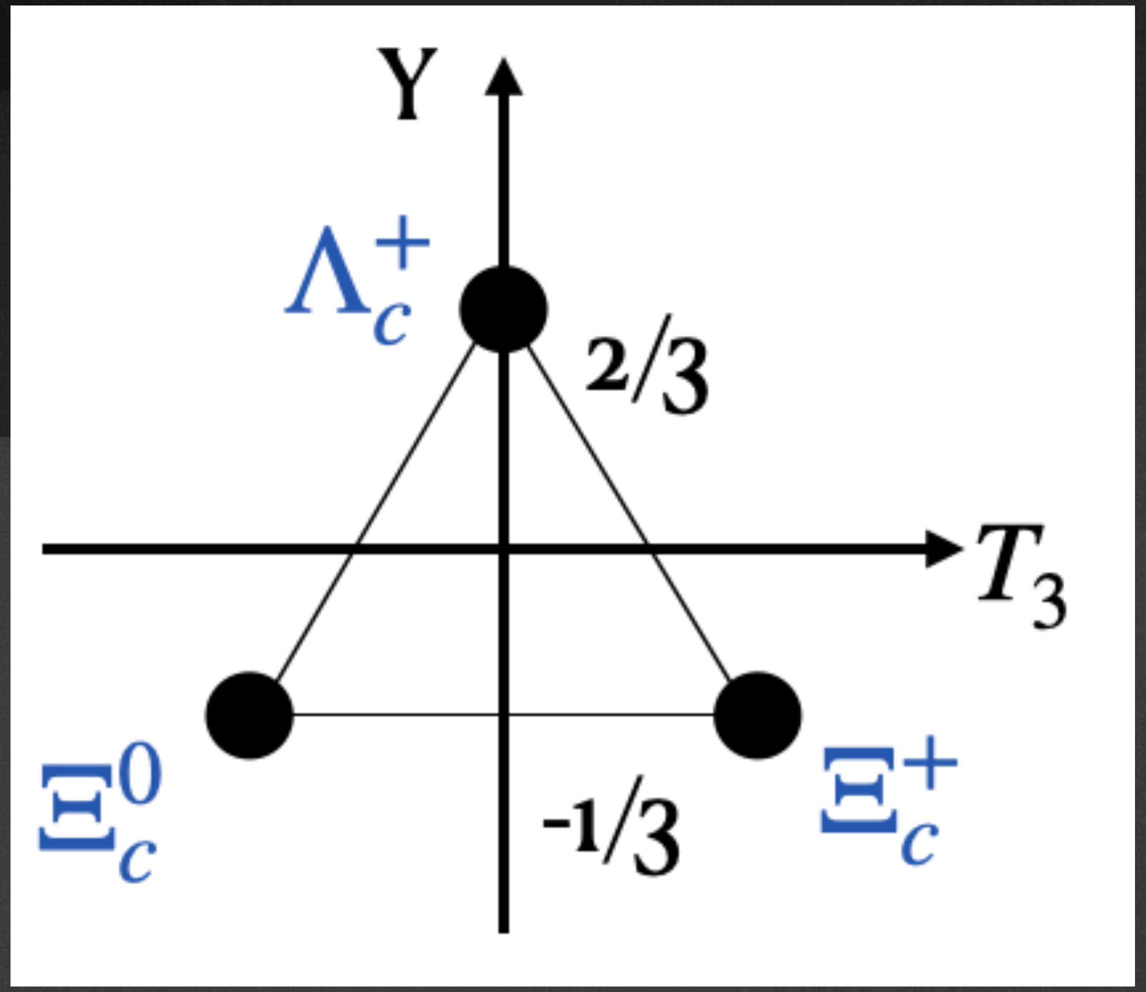
How about singly heavy baryon?



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

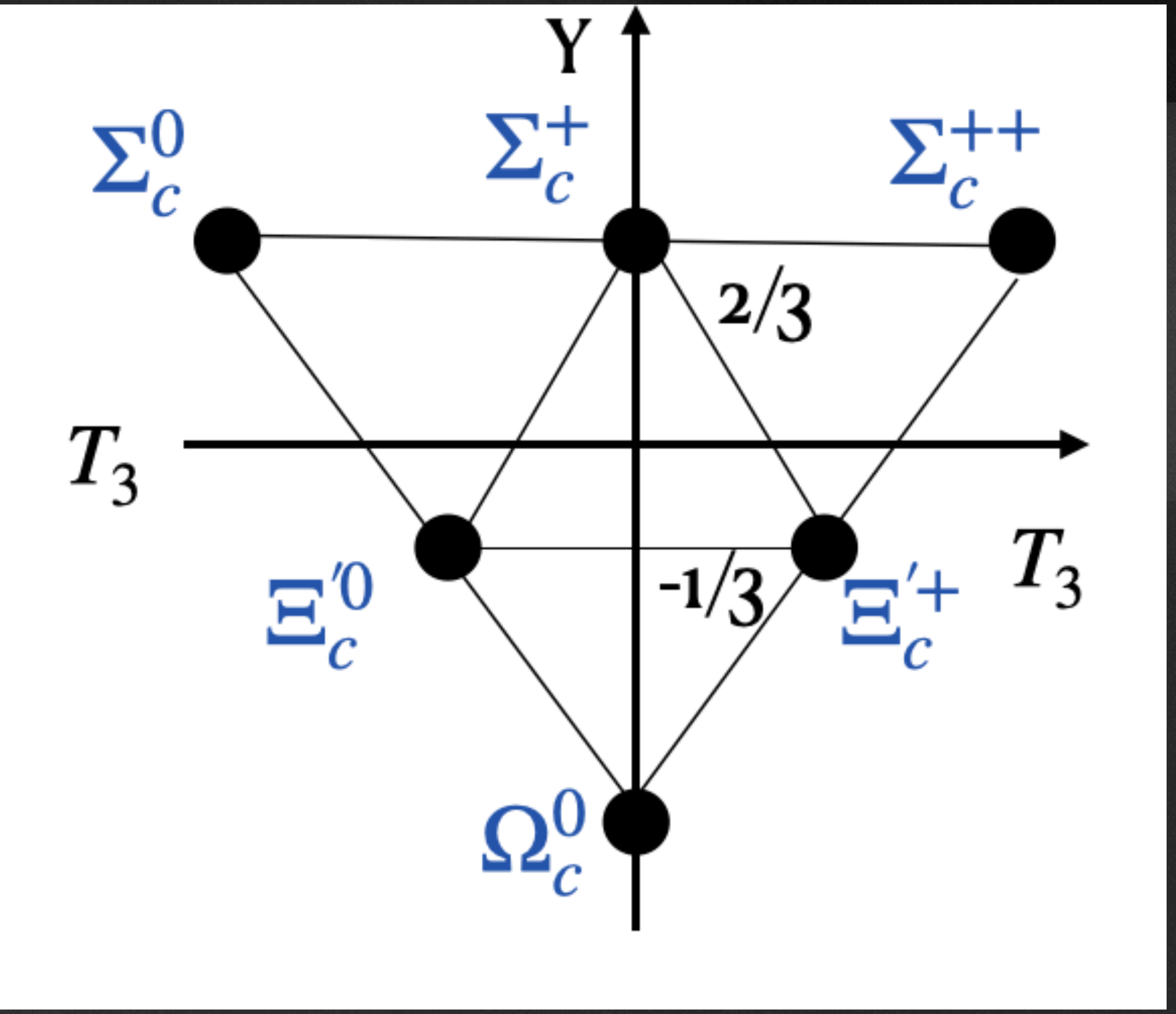
Heavy quark symmetry

$$3 \otimes 3 = \bar{3} \oplus 6$$



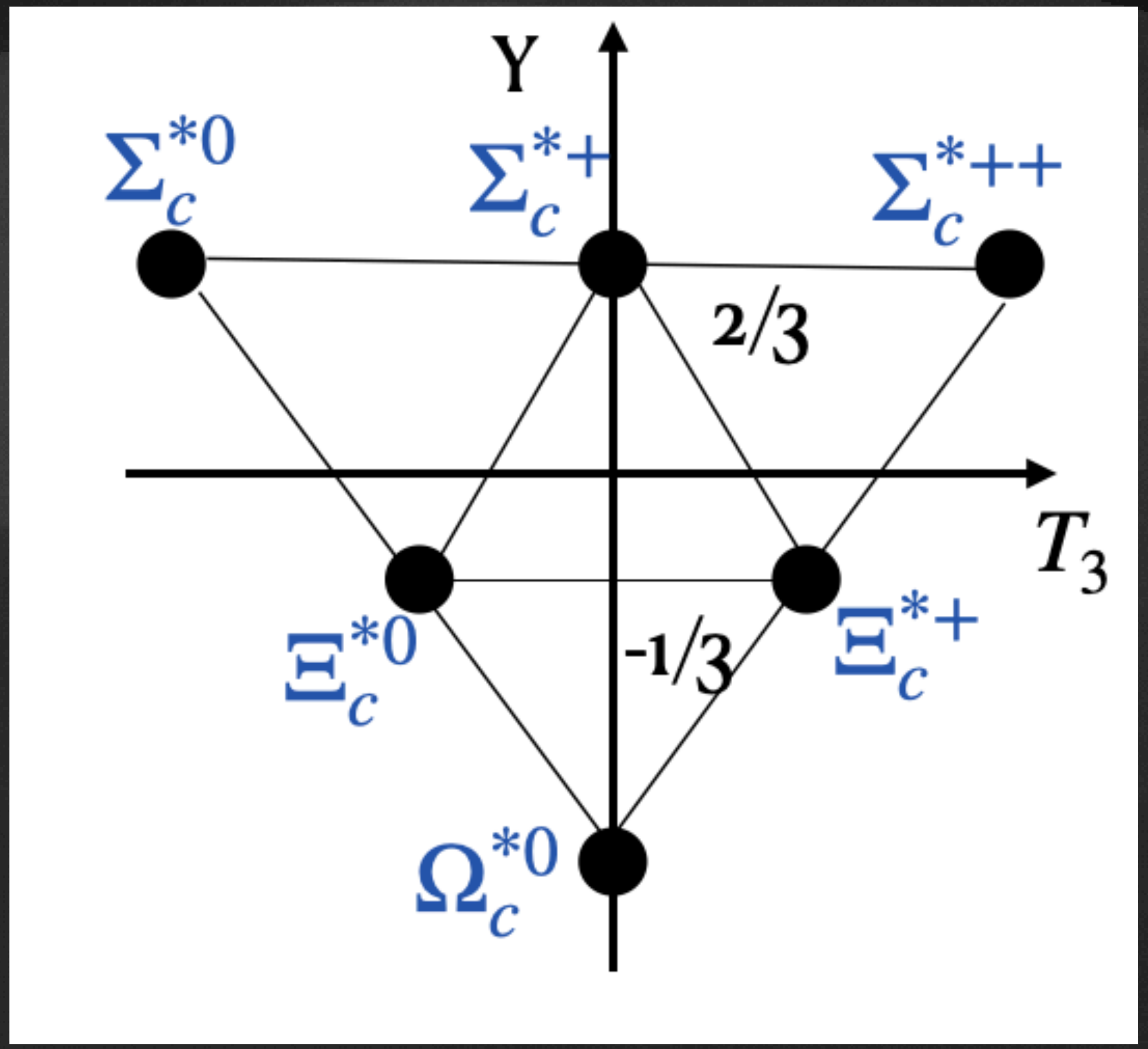
$[\bar{3}]$

$J = 1/2$



$[6]$

$J = 1/2$



$[6]$

$J = 3/2$

Decomposition of axial-vector transition FF

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

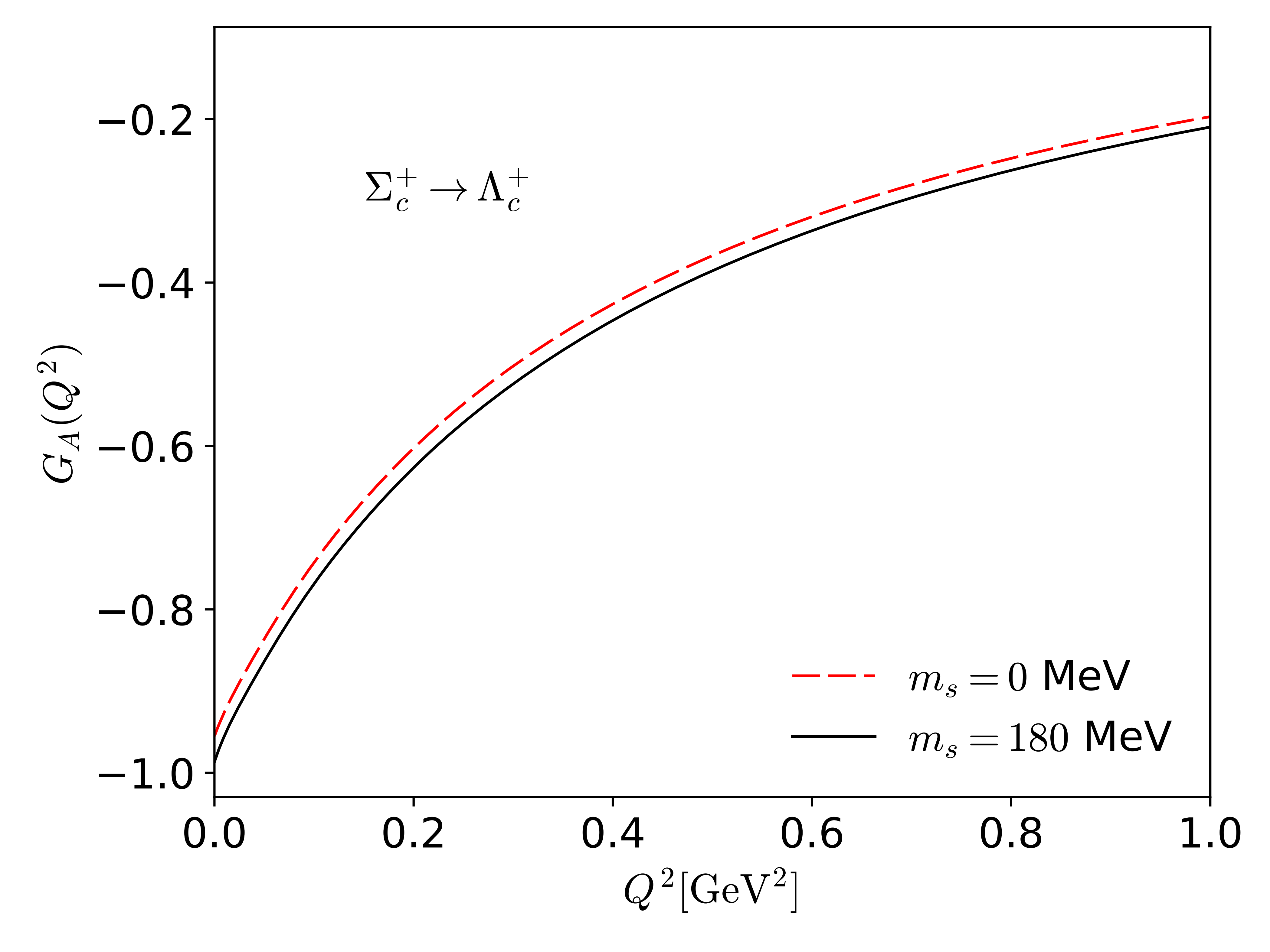
$$\langle B'_{1/2}(p_f, J_3^{'})|A_\mu^a(0)|B_{1/2}(p_i, J_3)\rangle = \bar{u}(p_f, J_3^{'})\left[G_A^{(a)}(q^2)\gamma_\mu + \frac{G_P^{(a)}(q^2)}{M'+M}q_\mu\right]\frac{\gamma_5}{2}u(p_i, J_3)$$

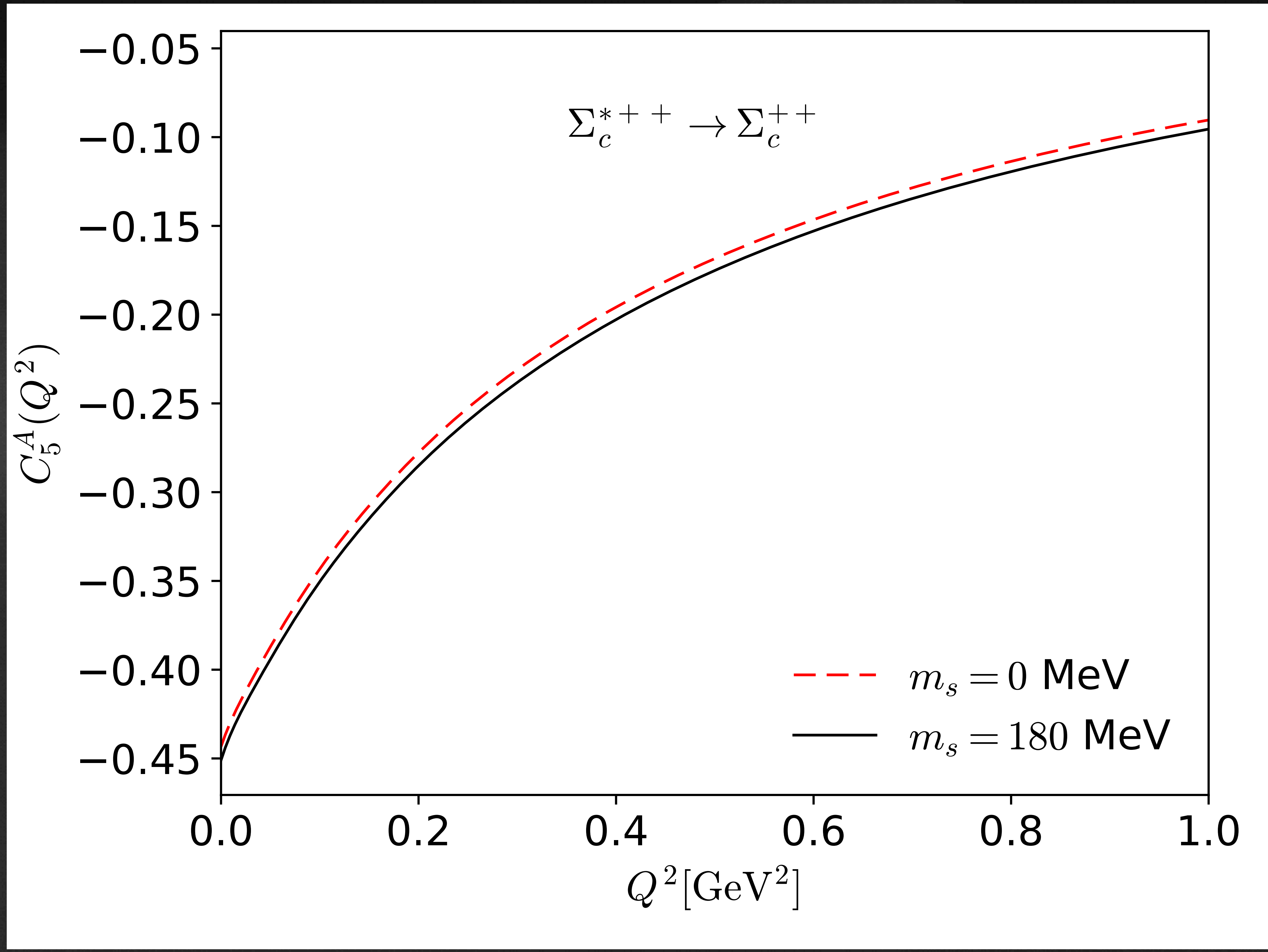
$$\langle B'_{\frac{1}{2}}(p', J'_3)|A_\mu^a(0)|B_{\frac{3}{2}}(p, J_3)\rangle$$

$$= \overline{u}(p', J'_3)\left[\left\{\frac{C_3^{A(a)}(q^2)}{M'}\gamma^\nu + \frac{C_4^{A(a)}(q^2)}{M'^2}p^\nu\right\}(g_{\alpha\mu}g_{\rho\nu} - g_{\alpha\rho}g_{\mu\nu})q^\rho \right.$$

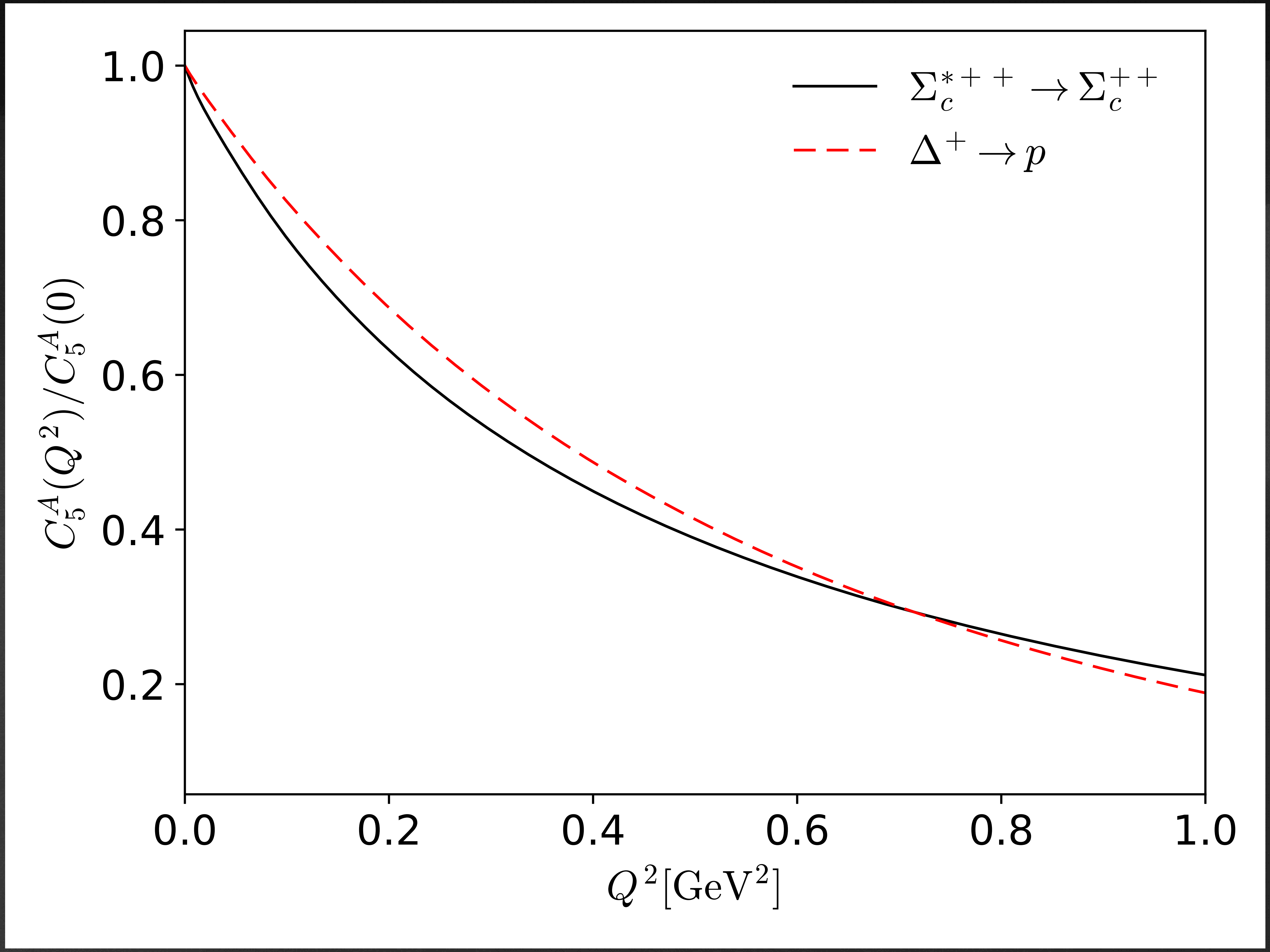
$$\left. + C_5^{A(a)}(q^2)g_{\alpha\mu} + \frac{C_6^{A(a)}(q^2)}{M'^2}q_\alpha q_\mu\right]u^\alpha(p, J_3)$$

Axial-vector transition FF of singly heavy baryons





Comparison of axial-vector transition FF of between light baryons and singly heavy baryons



Decay widths of singly heavy baryons

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!