Axial-vector transition form factors in the chiral quark-soliton model

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Motivation

Except for the Delta, the axial transitions for other baryon decuplet are not much known.

The axial-vector transition constant $C_5^A(0)$ can be directly related to the strong coupling constants for the baryon decuplet and octet.

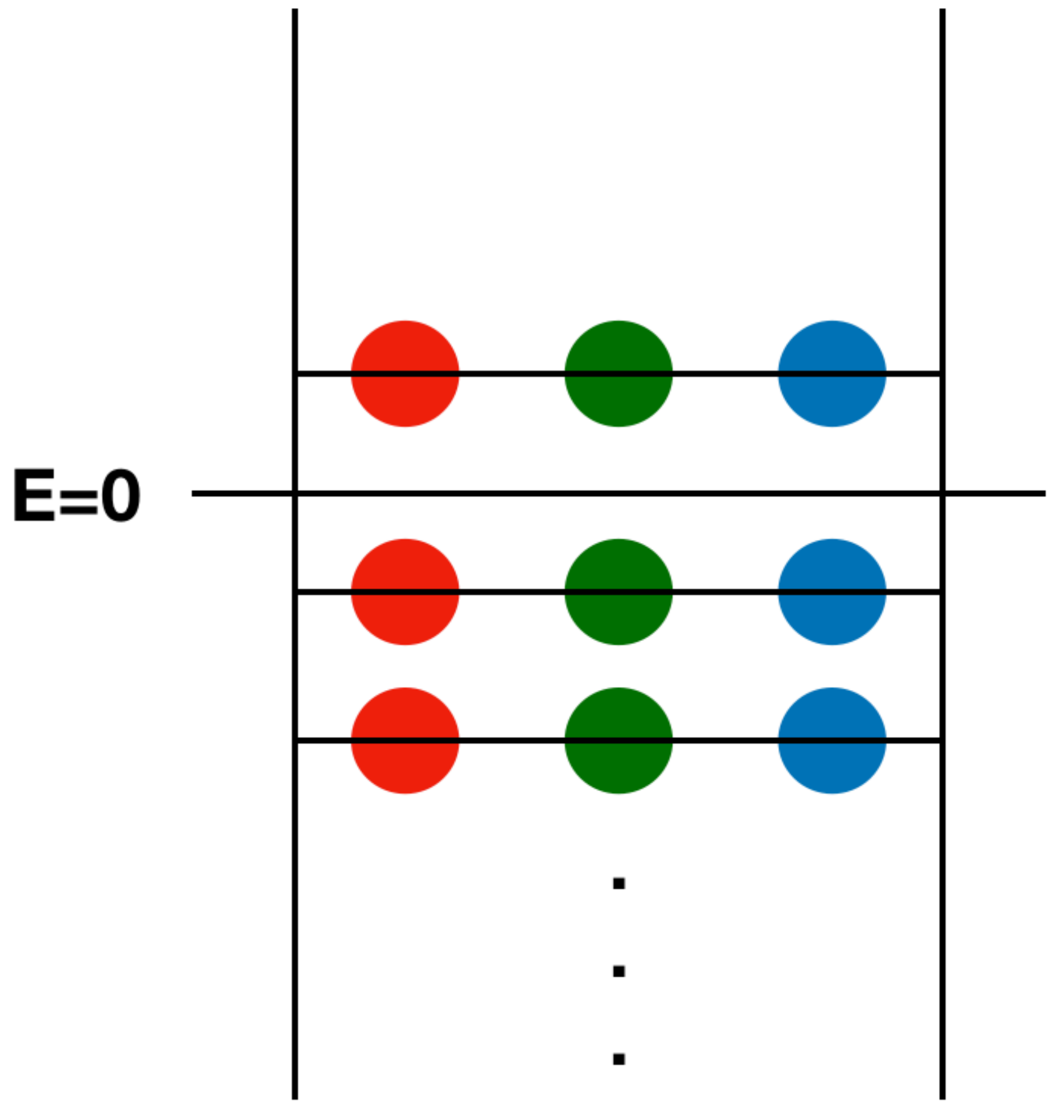
The axial-vector transition form factors have been studied within lattice QCD. Thus, the present work will shed yet a new light on the structure of the baryon decuplet in comparison with the lattice data.

Formalism

The chiral quark-soliton model starts with the following partition function,

$$Z_{\chi QSM} = \int D\psi D\psi^\dagger DU^a \exp\Big[-\int d^4x\psi^\dagger i\Big(i\partial\!\!\!/ + iMU^{\gamma_5} + i\hat{m}\Big)\psi\Big]$$
$$= \int DU^a \exp\Big[-N_c(\mathrm{Tr}\ln D(U^a) - \mathrm{Tr}\ln D_0)\Big]$$

$$\boxed{S_{eff}[U^a] = -N_c \mathrm{Tr}\ln D(U^a)}$$



$$D(U^a) = i\partial\!\!\!/ + iMU^{\gamma_5} + i\hat{m}$$

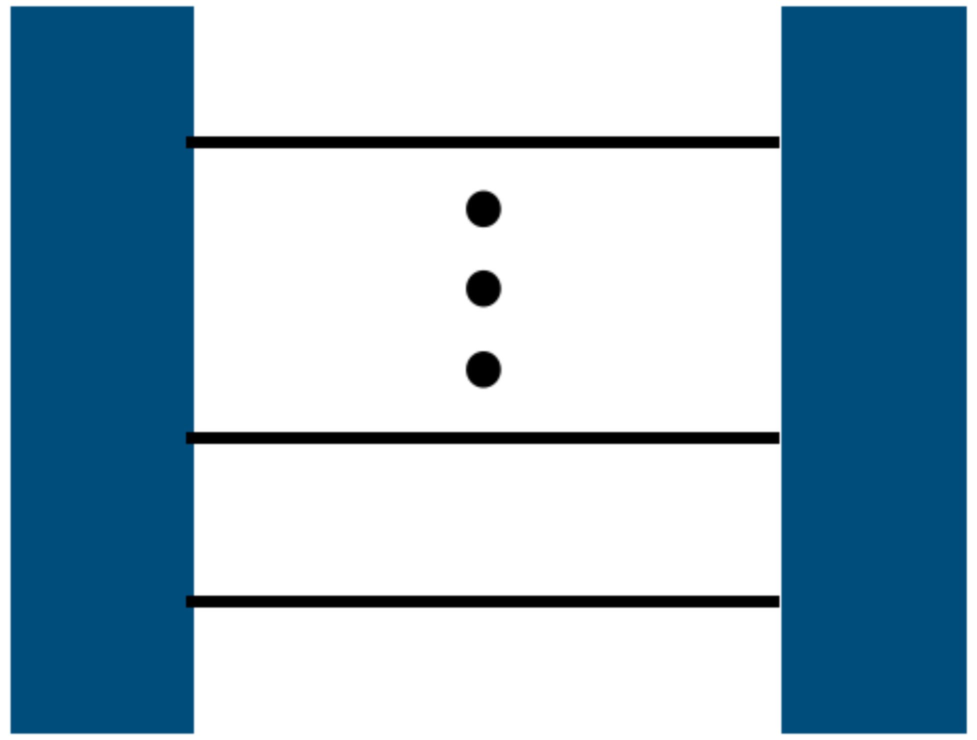
Formalism

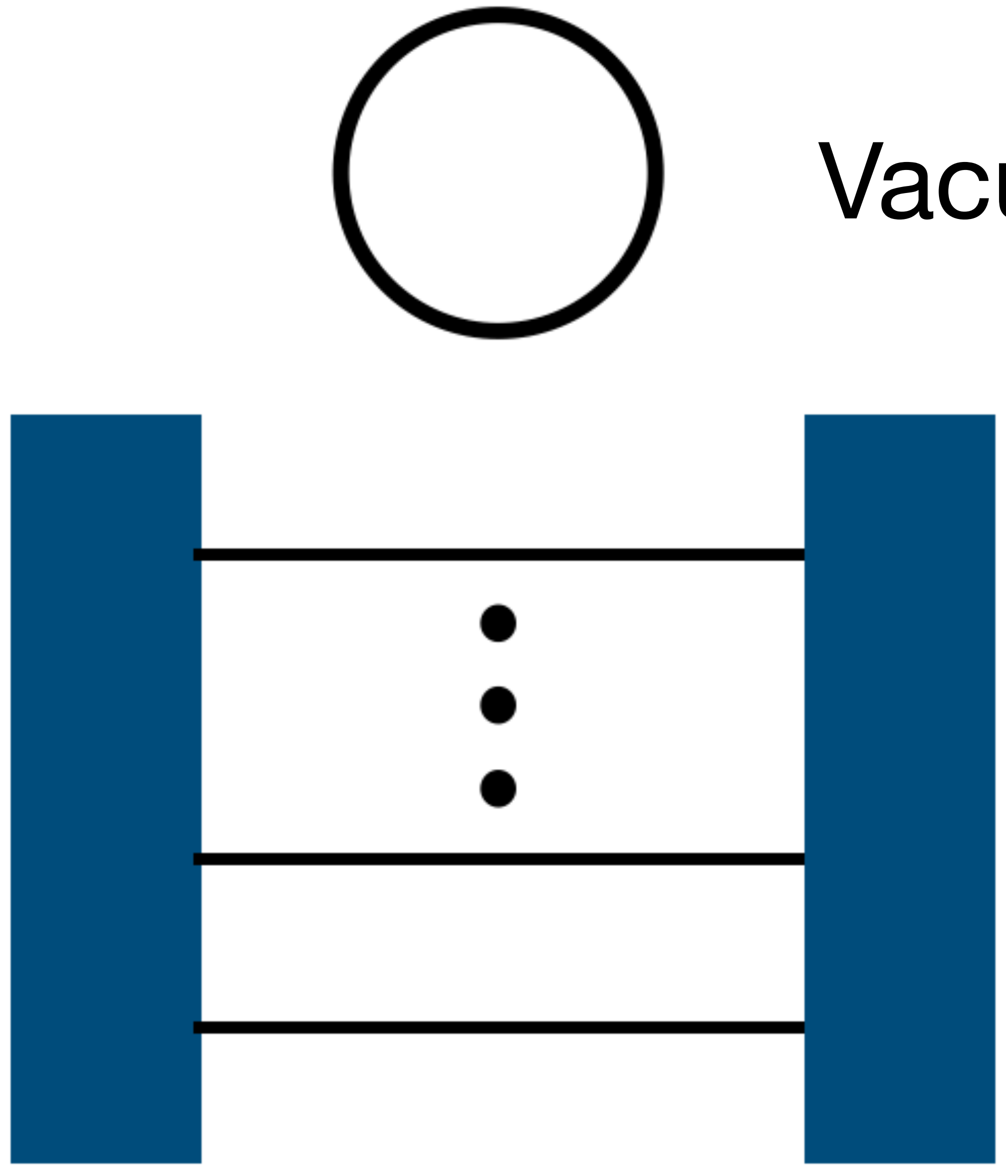
Large N_c limit

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

Hedgehog Ansatz $U^{\gamma_5} = e^{i\gamma^5 \vec{\pi}\cdot\vec{\tau}}$

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





Vacuum polarization

Formalism

$$\mathcal{L} = -M_{cl} + \frac{I_1}{2}\sum_{i=1}^{3}\Omega_E^i\Omega_E^i + \frac{I_2}{2}\sum_{a=4}^{7}\Omega_E^a\Omega_E^a + \frac{N_c}{2\sqrt{3}}i\Omega_E^8$$

↓ Zero-mode quantization

$$H_{coll} = H_{sym} + H_{sb}$$

$$H_{sym} = M_{cl} + \frac{1}{2I_1}\sum_{i=1}^{3}J_i^2 + \frac{1}{2I_2}\sum_{p=4}^{7}J_p^2,$$

$$H_{sb} = \alpha D_{88}^{(8)} + \beta\hat{Y} + \frac{\gamma}{\sqrt{3}}\sum_{i=1}^{3}D_{8i}^{(8)}\hat{J}_i$$

$$\alpha = \Big(-\frac{\Sigma_{\pi N}}{3m_0} + \frac{K_2}{I_2}Y'\Big)m_s$$

$$\beta = -\frac{K_2}{I_2}m_s$$

$$\gamma = 2\Big(\frac{K_1}{I_1} - \frac{K_2}{I_2}\Big)m_s$$

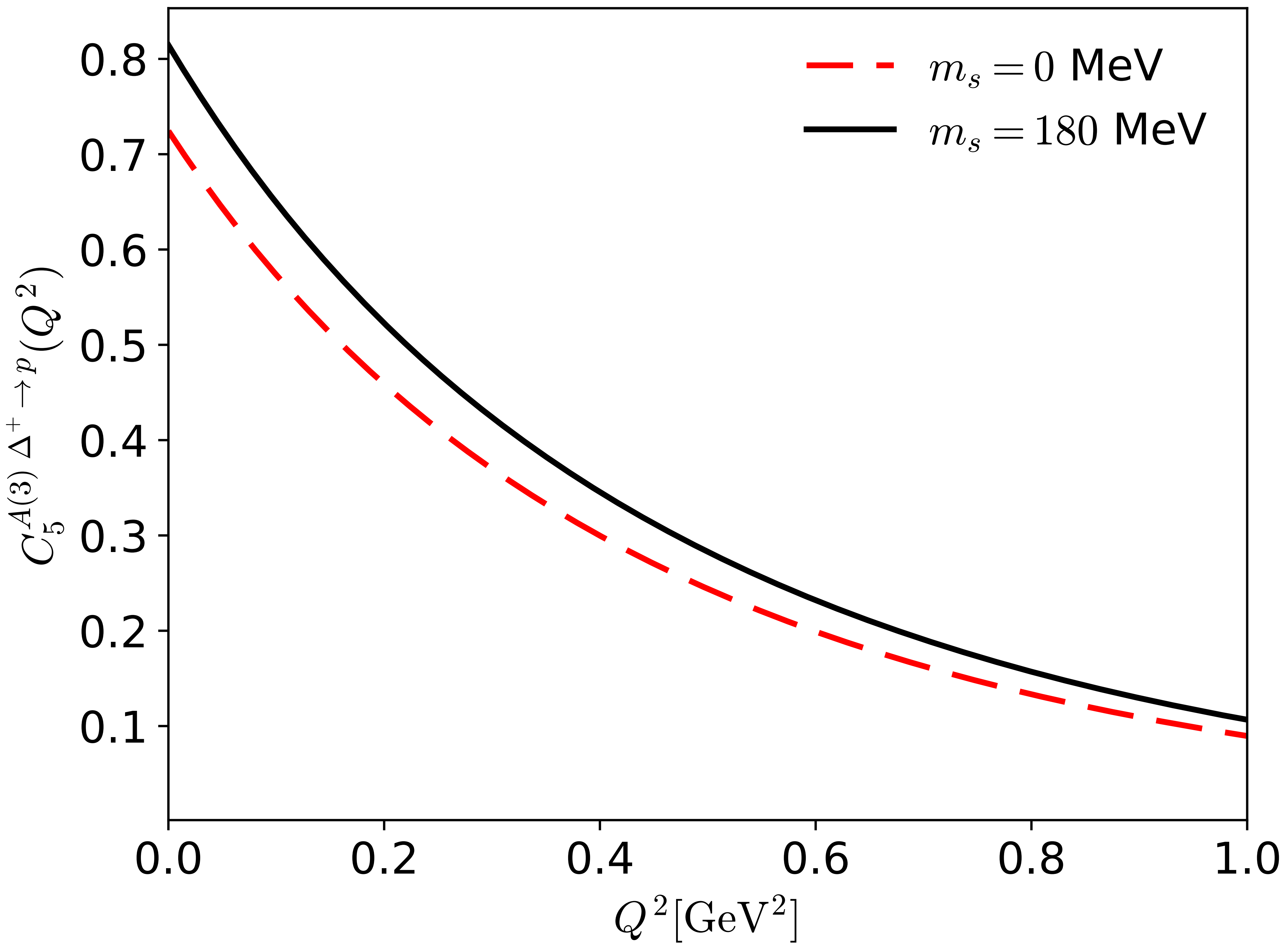
Formalism

The axial-vector transition form factor

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

Note that $C_5^A(q^2)$ is the most important observable because it can be related to the $g_{\pi N\Delta}$ by off diagonal Goldberger-Treiman relation.

Results



$$C_5^A(0) = 0.81$$

The difference between the $C_5^A(q^2)$ in case of $m_s = 180\mathrm{MeV}$ and one in case of $m_s = 0\mathrm{MeV}$ shows the SU(3) symmetry breaking effect.

Results

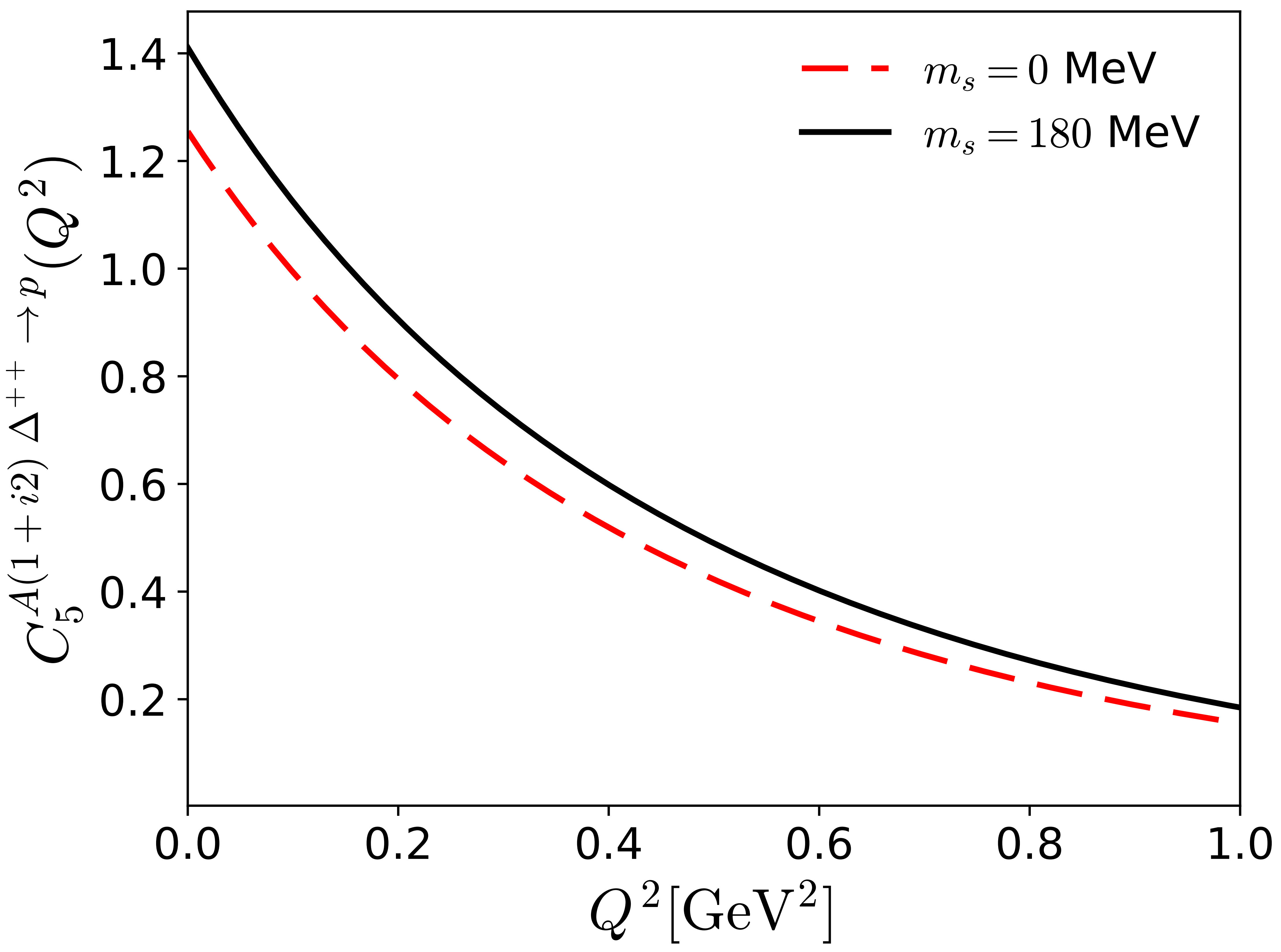
TABLE I. Numerical results for $C_5^{(3)B_{10}\to B_8}(0)$ in comparison with those from from lattice QCD(LQCD) [1], the relativistic quark model(RQM) [2] [3] [4], the Weinberg-Salam model(WSM) [5], the nonrelativistic quark model(NRQM) [6], the linear σ-model(LSM) and the cloudy bag model(CBM) [7], the chiral constituent quark model(χCQM) [8], the light-cone QCD sumrule(LCSR) [9], the nonlinear σ-model(NLSM) [10] and T2K experimental data(T2K) [11].

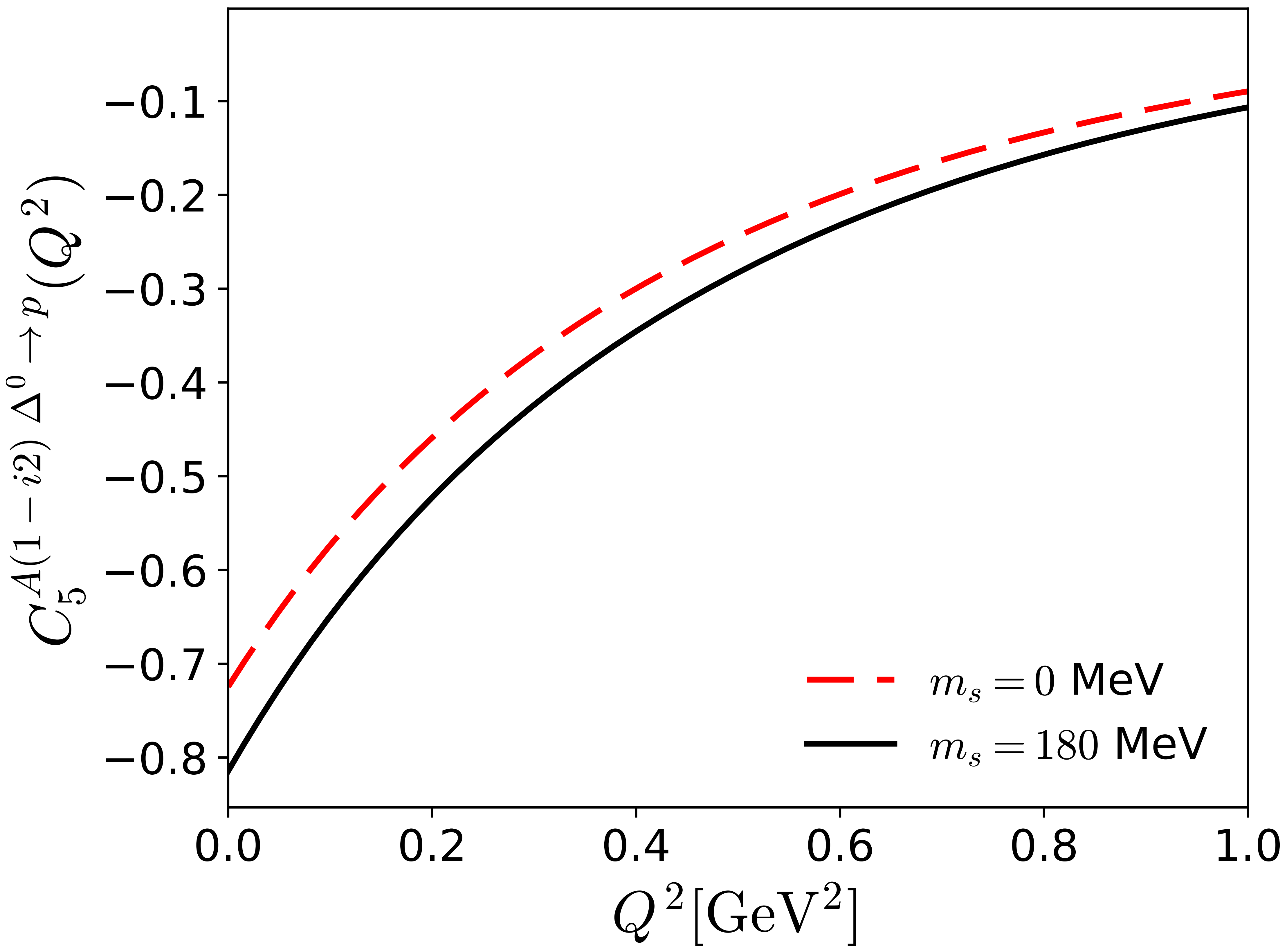
$C_5^{(3)B_{10}\to B_8}(0)$	$\Delta^+ \to p$	$\Delta^0 \to n$	$\Sigma^{*+} \to \Sigma^+$	$\Sigma^{*0} \to \Lambda$	$\Sigma^{*0} \to \Sigma^0$	$\Sigma^{*-} \to \Sigma^-$	$\Xi^{*0} \to \Xi^0$	$\Xi^{*-} \to \Xi^-$
$m_s = 180$ MeV	0.8145	0.8145	-0.4187	0.7241	0.0000	0.4187	-0.4202	0.4202
RQM1 [2]	0.97	-	-	-	-	-	-	-
RQM2 [3]	0.83	-	-	-	-	-	-	-
RQM3 [4]	0.97	-	-	-	-	-	-	-
WSM [5]	1.2	-	-	-	-	-	-	-
NRQM [6]	1.17	-	-	-	-	-	-	-
LSM [7]	1.53							
CBM [7]	0.81							
χCQM [8]	0.93							
LCSR [9]	1.14 ± 0.20							
NLSM [10]	1.12 ± 0.11							
T2K(Prefit) [11]	0.96 ± 0.15							
T2K(Postfit) [11]	0.98 ± 0.06							

[1] C. Alexandrou, G. Koutsou, J. W. Negele, Y. Proestos and A. Tsapalis, Phys. Rev. D **83** (2011), 014501
[2] F. Ravndal, Nuovo Cim. A **18** (1973), 385-415
[3] A. Le Yaouanc, L. Oliver, O. Pene, J. C. Raynal and C. Longuemare, Phys. Rev. D **15** (1977), 2447
[4] J. G. Korner, T. Kobayashi and C. Avilez, Phys. Rev. D **18** (1978), 3178
[5] L. M. Nath, K. Schilcher and M. Kretzschmar, Phys. Rev. D **25** (1982), 2300
[6] J. Liu, N. C. Mukhopadhyay and L. s. Zhang, Phys. Rev. C **52** (1995), 1630-1647
[7] B. Golli, S. Sirca, L. Amoreira and M. Fiolhais, Phys. Lett. B **553** (2003), 51-60
[8] D. Barquilla-Cano, A. J. Buchmann and E. Hernandez, Phys. Rev. C **75** (2007), 065203 [erratum: Phys. Rev. C **77** (2008), 019903]
[9] A. Kucukarslan, U. Ozdem and A. Ozpineci, Nucl. Phys. B **913** (2016), 132-150
[10] L. Alvarez-Ruso, E. Hernández, J. Nieves and M. J. Vicente Vacas, Phys. Rev. D **93** (2016) no.1, 014016
[11] K. Abe *et al.* [T2K], Phys. Rev. D **103** (2021) no.11, 112008

Results

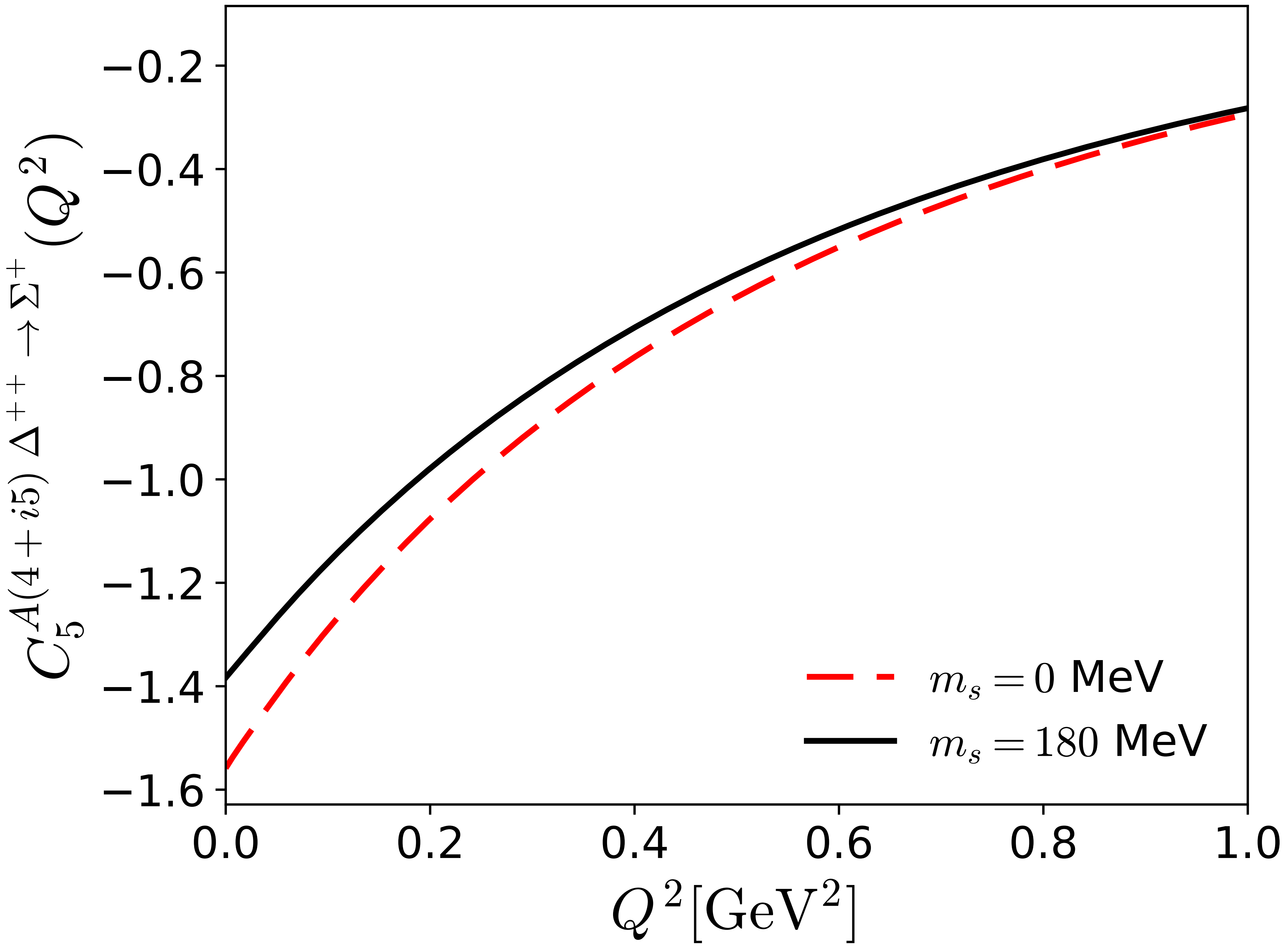
Strangeness conserving process

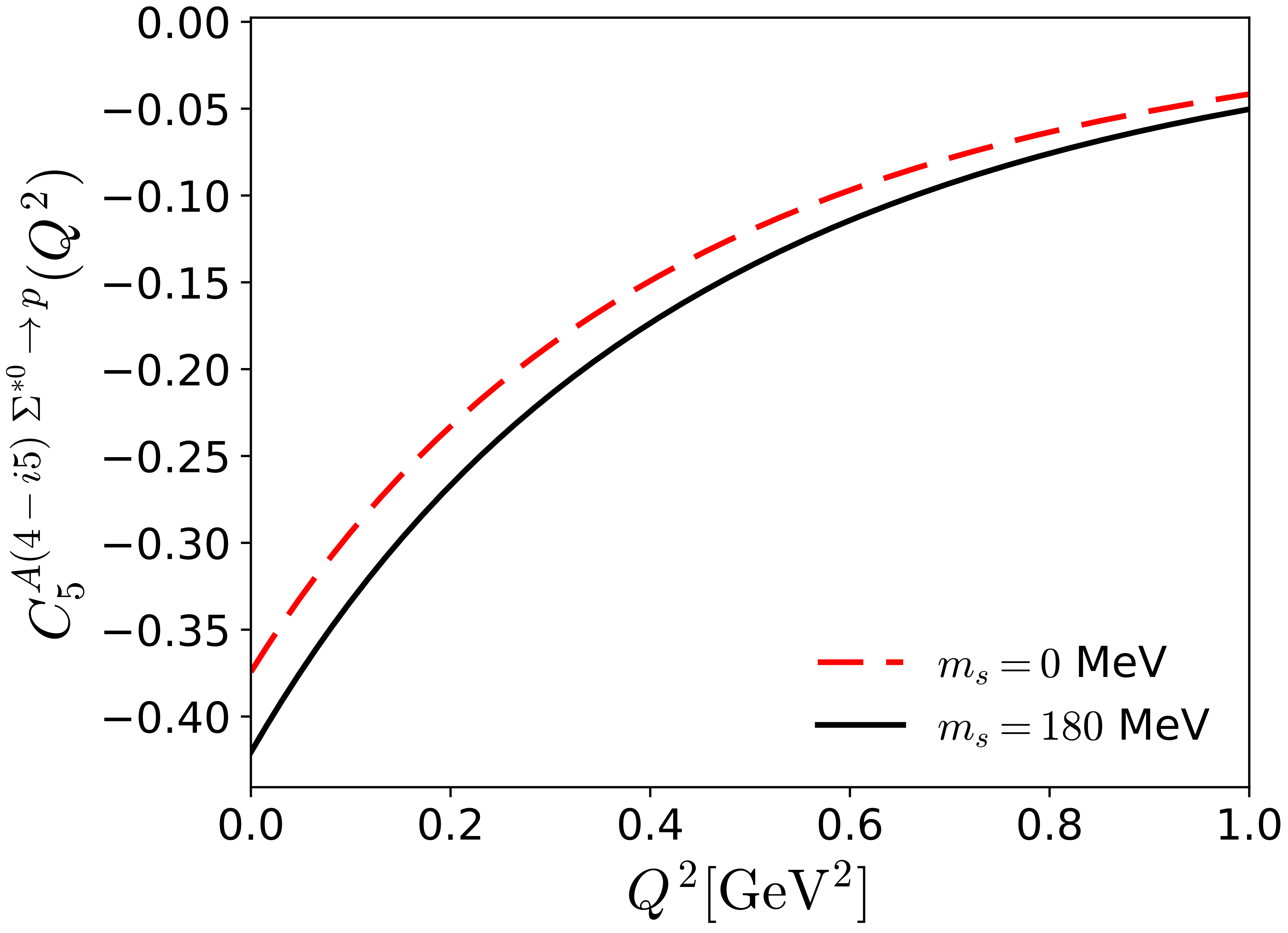




Results

Strangeness changing process





Conclusion

- We investigate the axial-vector transition form factors from the baryon decuplet to the octet in the flavor conserving and the flavor changing decay modes within the pion mean field approach.
- We compare the axial-vector transition constants for $\Delta^+ \to p$ decay with those of other theoretical and the experimental group.

Thank you very much!