QCD sum rules analysis of weak decays of doubly heavy baryons: the $b \to c$ processes

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1. Introduction

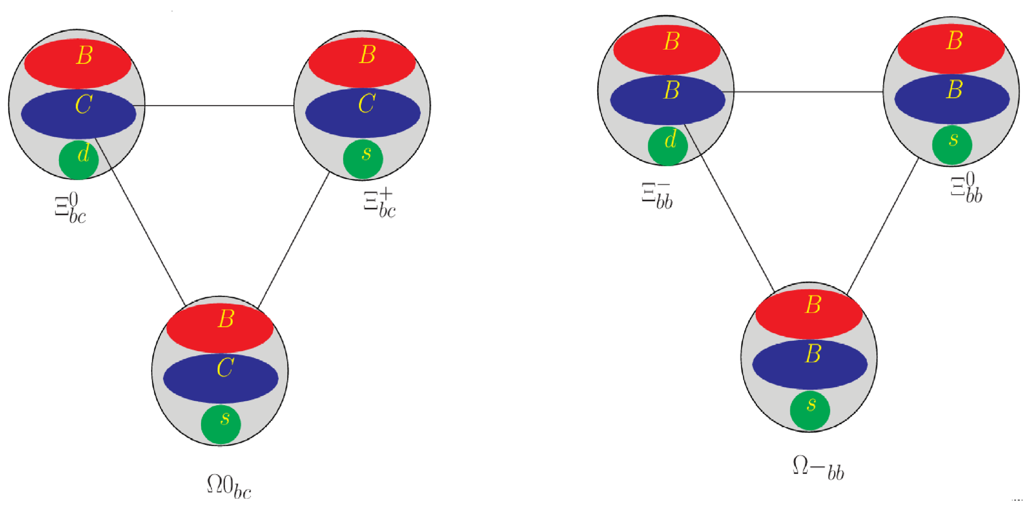
A comprehensive study of $b \to c$ weak decays of doubly heavy baryons is presented in this poster. The transition form factors as well as the pole residues of the initial and final states are respectively obtained by investigating the three-point and two-point correlation functions in QCD sum rules. We will consider the following processes ($q = u/d$):

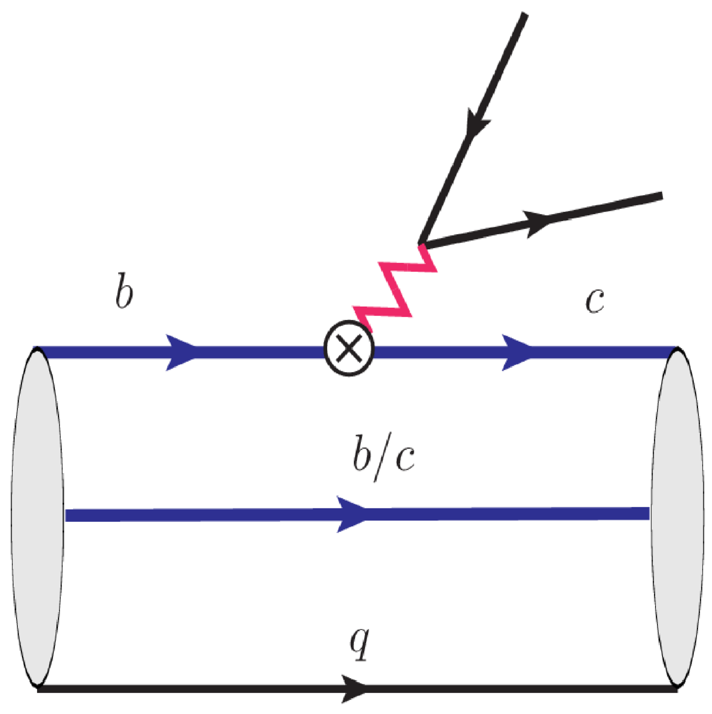
- the bb sector,

$$\Xi_{bb}(bbq) \to \Xi_{bc}(bcq), \qquad \Omega_{bb}(bbs) \to \Omega_{bc}(bcs),$$

- the bc sector,

$$\Xi_{bc}(bcq) \to \Xi_{cc}(ccq), \qquad \Omega_{bc}(bcs) \to \Omega_{cc}(ccs).$$





The obtained form factors are then applied to a phenomenological analysis of semi-leptonic decays. The transition matrix element can be parametrized by the so-called helicity form factors $f_{0,+,\perp}$ and $g_{0,+,\perp}$ [1]

$$\begin{aligned}\langle \mathcal{B}_2(P_2)|(V-A)_\mu|\mathcal{B}_1(P_1)\rangle = & \ \bar u(P_2,s_2)\left[\frac{q_\mu}{q^2}(M_1-M_2)f_0(q^2)+\frac{M_1+M_2}{Q_+}\left((P_1+P_2)_\mu-(M_1^2-M_2^2)\frac{q_\mu}{q^2}\right)f_+(q^2)+\left(\gamma_\mu-\frac{2M_2}{Q_+}P_{1\mu}-\frac{2M_1}{Q_+}P_{2\mu}\right)f_\perp(q^2)\right]u(P_1,s_1)\\ & - \bar u(P_2,s_2)\gamma_5\left[\frac{q_\mu}{q^2}(M_1+M_2)g_0(q^2)+\frac{M_1-M_2}{Q_-}\left((P_1+P_2)_\mu-(M_1^2-M_2^2)\frac{q_\mu}{q^2}\right)g_+(q^2)+\left(\gamma_\mu+\frac{2M_2}{Q_-}P_{1\mu}-\frac{2M_1}{Q_-}P_{2\mu}\right)g_\perp(q^2)\right]u(P_1,s_1),\end{aligned}$$

with $Q_\pm = (M_1 \pm M_2)^2 - q^2$. These form factors can be extracted using the three-point correlation functions in QCDSR.

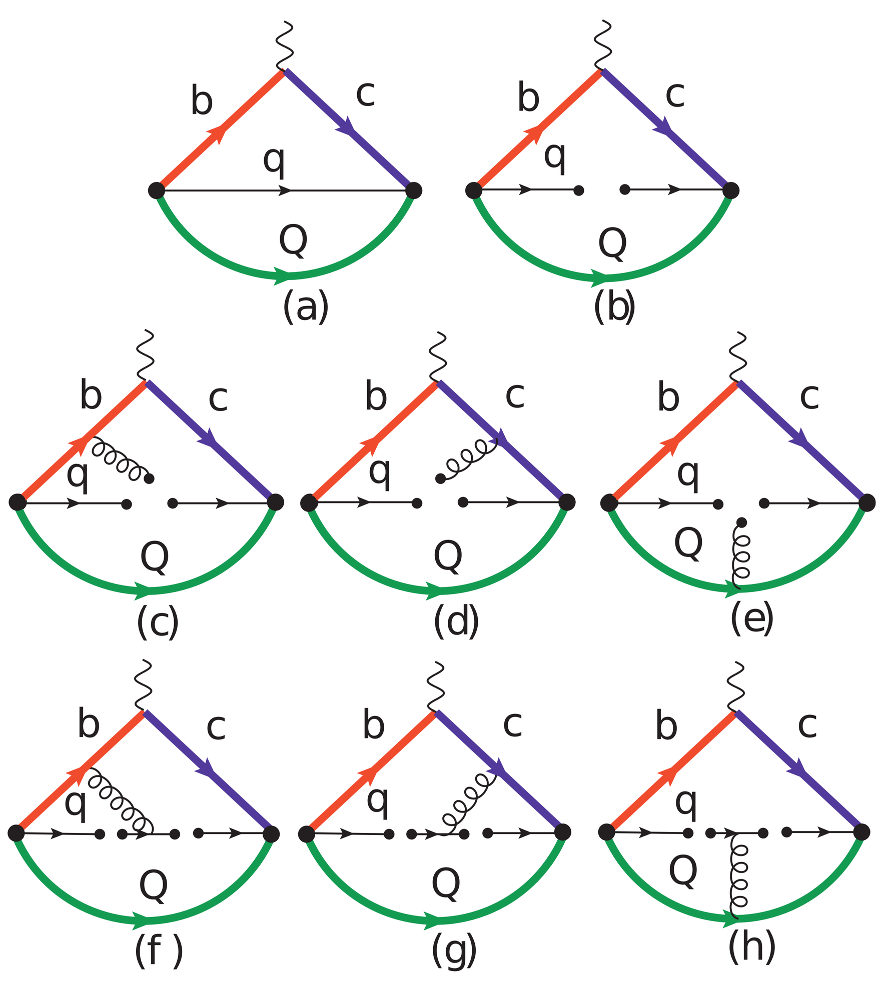
2. The correction functions

The masses , pole residues and transition form factors of the doubly heavy baryon $\mathcal{B}_{Q_1Q_2q_3}$ can be obtained by calculating the following two-point and three-point correlation function

$$\Pi(q) = i\int d^4x e^{iq\cdot x}\langle 0|T\left[J_{\mathcal{B}_{Q_1Q_2q_3}}(x)\bar J_{\mathcal{B}_{Q_1Q_2q_3}}(0)\right]|0\rangle.$$

$$\Pi_\mu^{V,A}(P_1,P_2) = i^2\int d^4x d^4y e^{-iP_1\cdot x+iP_2\cdot y}\langle 0|T\{J_{\mathcal{B}_{cQq}}(y)(V_\mu,A_\mu)(0)\bar J_{\mathcal{B}_{bQq}}(x)\}|0\rangle.$$

The Feynman diagram of three-point correction functions up to dimension-6 are shown as follows



3. masses and pole residues

Our predictioins of pole residues and masses with the Leading Log corrections are collected in Table below. In this Table, our predictions for the masses are also compared with those from Lattice QCD [2]

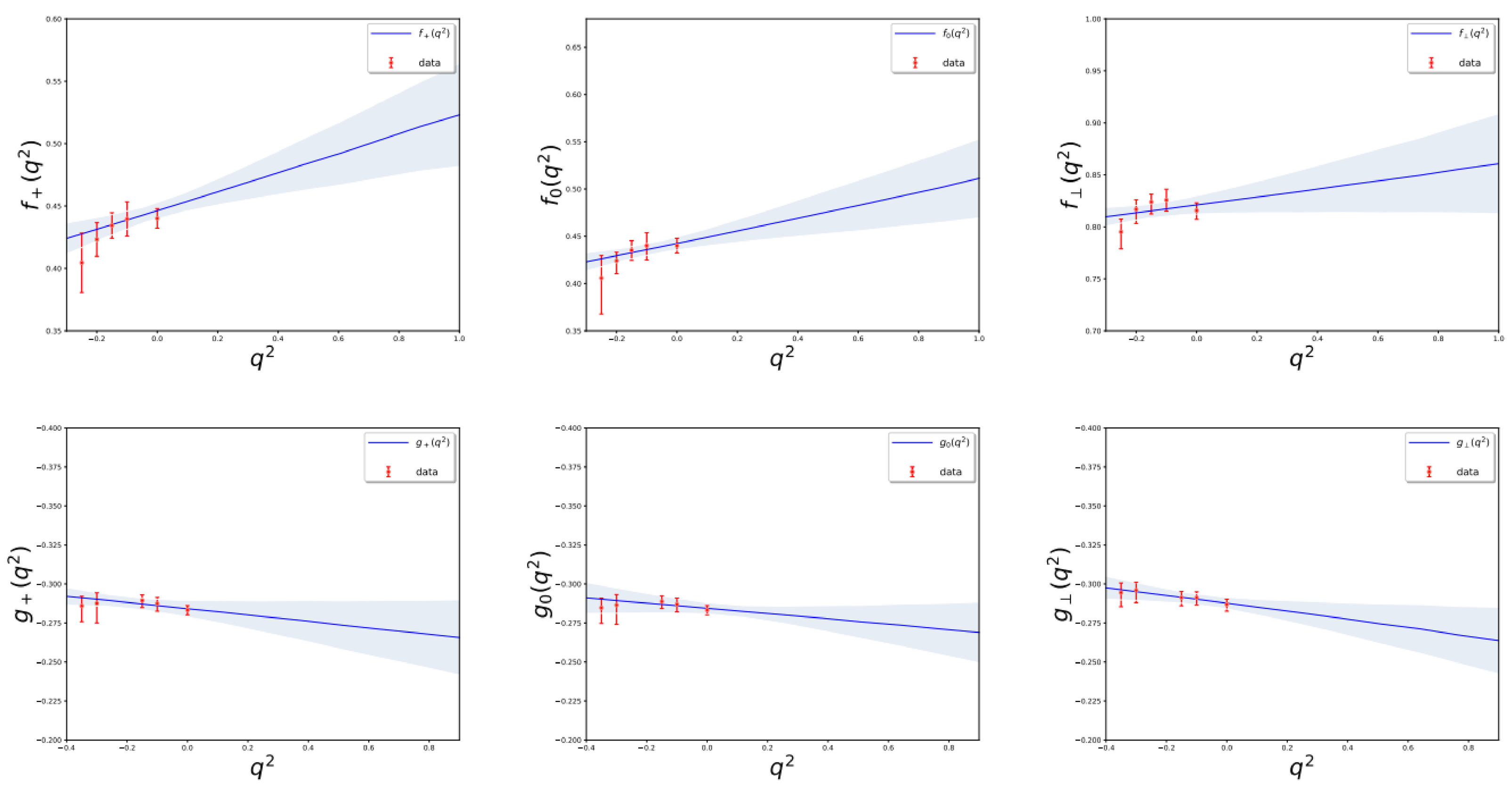
Baryon	Pole residues	Masses	Masses in Lattice QCD [2]
Ξ_{bb}	$0.736^{+0.000}_{-0.000}(T^2)^{+0.053}_{-0.052}(s_0)$	$10.152^{+0.007}_{-0.009}(T^2)^{+0.079}_{-0.080}(s_0)$	10.143
Ω_{bb}	$0.825^{+0.000}_{-0.000}(T^2)^{+0.060}_{-0.059}(s_0)$	$10.279^{+0.006}_{-0.007}(T^2)^{+0.080}_{-0.081}(s_0)$	10.273
Ξ_{bc}	$0.369^{+0.000}_{-0.000}(T^2)^{+0.028}_{-0.027}(s_0)$	$6.935^{+0.009}_{-0.007}(T^2)^{+0.080}_{-0.081}(s_0)$	6.943
Ω_{bc}	$0.388^{+0.000}_{-0.000}(T^2)^{+0.030}_{-0.029}(s_0)$	$6.998^{+0.006}_{-0.008}(T^2)^{+0.081}_{-0.081}(s_0)$	6.998
Ξ_{cc}	$0.130^{+0.000}_{-0.000}(T^2)^{+0.011}_{-0.011}(s_0)$	$3.629^{+0.010}_{-0.012}(T^2)^{+0.078}_{-0.079}(s_0)$	3.621
Ω_{cc}	$0.149^{+0.000}_{-0.000}(T^2)^{+0.013}_{-0.012}(s_0)$	$3.743^{+0.009}_{-0.011}(T^2)^{+0.079}_{-0.080}(s_0)$	3.738

4. Transition form factors

In our analysis, we calculate the form factors at small q^2, and then fit the data with the following formula

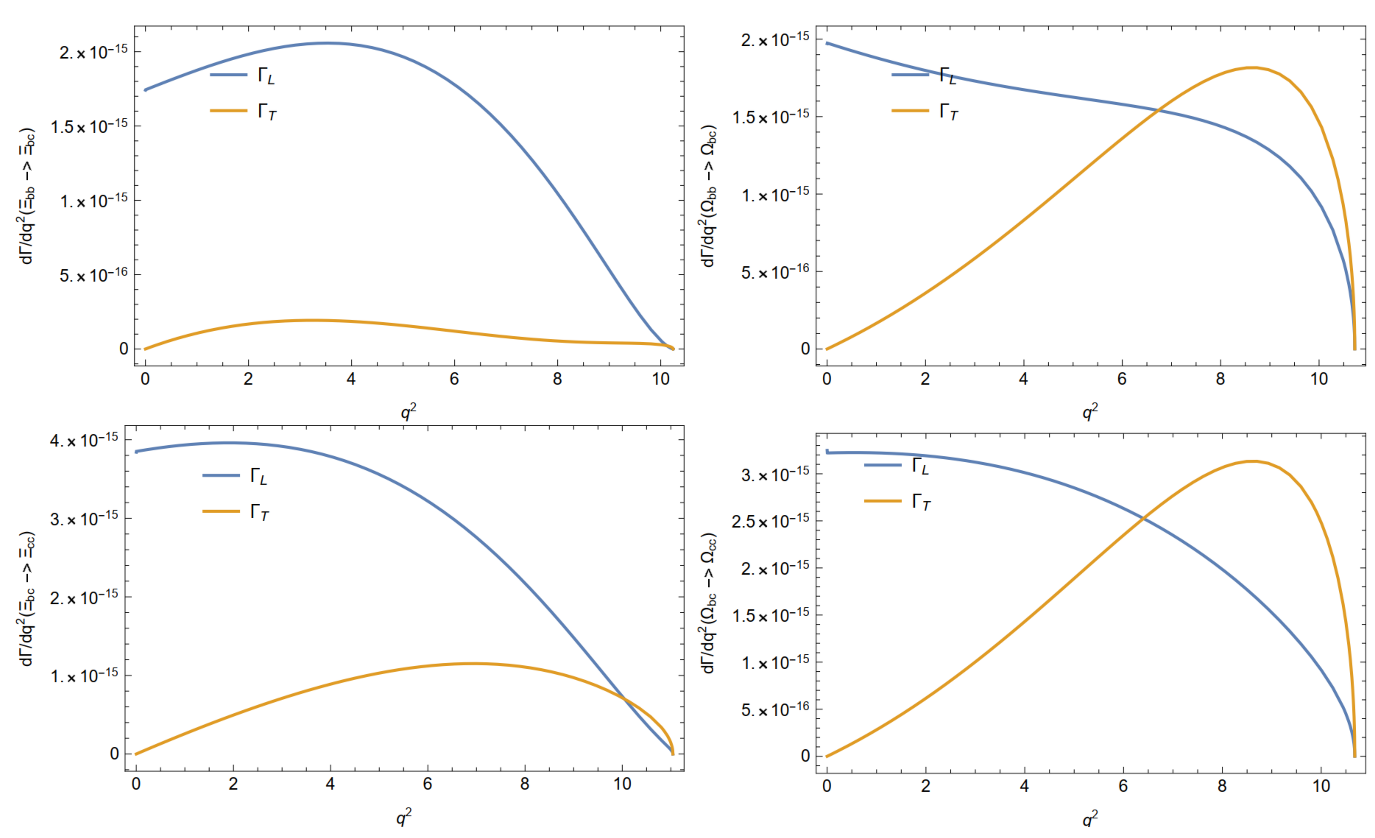
$$f(q^2) = \frac{1}{1-q^2/(m_{\rm pole})^2}(a+bz(q^2)) \qquad (1)$$

The nonlinear least-χ^2 (lsq) method is used in our analysis [3].We give the fitting results of $\Xi_{bb} \to \Xi_{bc}$ processes as



5. Phenomenological applications

Using the helicity amplitude method, our predictions of the decay widths are given as follows:



channel	decay width(10^{-14}GeV)
$\Gamma(\Xi_{bb} \to \Xi_{bc})$	$1.955 \pm 0.685(T_1^2,T_2^2) \pm 1.673(s_1^0,s_2^0)$
$\Gamma_L(\Xi_{bb} \to \Xi_{bc})$	$1.728 \pm 0.658(T_1^2,T_2^2) \pm 1.363(s_1^0,s_2^0)$
$\Gamma_T(\Xi_{bb} \to \Xi_{bc})$	$0.227 \pm 0.175(T_1^2,T_2^2) \pm 0.342(s_1^0,s_2^0)$
$\Gamma(\Omega_{bb} \to \Omega_{bc})$	$3.005 \pm 0.780(T_1^2,T_2^2) \pm 4.932(s_1^0,s_2^0)$
$\Gamma_L(\Omega_{bb} \to \Omega_{bc})$	$1.854 \pm 0.670(T_1^2,T_2^2) \pm 2.363(s_1^0,s_2^0)$
$\Gamma_T(\Omega_{bb} \to \Omega_{bc})$	$1.151 \pm 0.382(T_1^2,T_2^2) \pm 2.562(s_1^0,s_2^0)$
$\Gamma(\Xi_{bc} \to \Xi_{cc})$	$4.174 \pm 0.796(T_1^2,T_2^2) \pm 4.933(s_1^0,s_2^0)$
$\Gamma_L(\Xi_{bc} \to \Xi_{cc})$	$3.260 \pm 0.730(T_1^2,T_2^2) \pm 4.272(s_1^0,s_2^0)$
$\Gamma_T(\Xi_{bc} \to \Xi_{cc})$	$0.914 \pm 0.279(T_1^2,T_2^2) \pm 0.66(s_1^0,s_2^0)$
$\Gamma(\Omega_{bc} \to \Omega_{cc})$	$4.799 \pm 1.095(T_1^2,T_2^2) \pm 4.385(s_1^0,s_2^0)$
$\Gamma_L(\Omega_{bc} \to \Omega_{cc})$	$2.762 \pm 0.676(T_1^2,T_2^2) \pm 2.931(s_1^0,s_2^0)$
$\Gamma_T(\Omega_{bc} \to \Omega_{cc})$	$2.037 \pm 0.867(T_1^2,T_2^2) \pm 1.454(s_1^0,s_2^0)$

6. References

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[3] P. Lepage and C. Gohlke, gplepage/lsqfit: lsqfit version 11.7, Zenodo. http://doi.org/10.5281/zenodo.4037174