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Doubly heavy Baryons from QCD Spectral Sum Rules

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Abstract

We consider the ratios of doubly heavy baryon masses using Double Ratios of Sum Rules (DRSR), which are more accurate than the usual simple ratios used for getting hadron masses. Our results are comparable with the ones from potential models. In our approach, the α_s corrections induced by the anomalous dimensions of the correlators are the main sources of the $\Xi^*_{QQ} - \Xi_{QQ}$ mass-splittings, which seem to indicate a $1/M_Q$ behaviour and can only allow the electromagnetic decay $\Xi^*_{QQ} \to \Xi_{QQ} + \gamma$ but not to $\Xi_{QQ} + \pi$. Our results also show that the SU(3) mass-splittings are (almost) independent of the spin of the baryons and behave approximately like $1/M_Q$, which could be understood from the QCD expressions of the corresponding two-point correlator. Our results can improved by including radiative corrections to the SU(3) breaking terms and can be tested, in the near future, at Tevatron and LHCb.

Keywords: QCD spectral sum rules, baryon spectroscopy, heavy quarks.

1. Introduction

In a previous paper [1], we have considered, using Double Ratios (DRSR) [2] of QCD spectral sum rules (QSSR) [3, 4], the splittings due to SU(3) breakings of the baryons made with one heavy quark. This project has been pursued in the case of doubly heavy baryons in [5], which will be reviewed in this talk.
The absolute values of the doubly heavy baryon masses of spin 1/2 ($\Xi_{QQ} \equiv QQu$) and spin 3/2 ($\Xi^*_{QQ} \equiv QQu$) have been obtained using QCD spectral sum rules (QSSR) (for the first time) in [6] with the results in GeV:

$$M_{\Xi^*_{cc}} = 3.58(5) \quad , \quad M_{\Xi^*_{bb}} = 10.33(1.09)\,, \qquad M_{\Xi_{cc}} = 3.48(6) \quad , \quad M_{\Xi_{bb}} = 9.94(91)\,, \tag{1}$$

and in [7]:

$$M_{\Xi_{bcu}} = 6.86(28)\,. \tag{2}$$

More recently [8, 9], some results have been obtained using some particular choices of the interpolating currents. The predictions for $M_{\Xi^*_{cc}}$ and $M_{\Xi_{cc}}$ are in good agreement with the experimental candidate $M_{\Xi_{cc}} = 3518.9$ MeV [10]. In the following, we shall improve these previous predictions using the DRSR for estimating the ratio of the 3/2 over the 1/2 baryon masses as well as their splittings due to SU(3) breakings, which we shall compare with some potential model predictions [7, 11–13].

2. The Interpolating Currents

• **For the spin 1/2 (QQq) baryons** , and following Ref. [6], we work with the lowest dimension currents:

$$J_{\Xi_Q} = \epsilon_{\alpha\beta\lambda}\left[(Q^T_\alpha C\gamma_5 q_\beta) + b(Q^T_\alpha C q_\beta)\gamma_5\right] Q_\lambda, \tag{3}$$

where $q \equiv d, s$ are light quark fields, $Q \equiv c, b$ are heavy quark fields, b is *a priori* an arbitrary mixing parameter. Its value has been found to be: $b = -1/5$, in the case of light baryons [14] and in the range [1, 15, 16]:

$$-0.5 \le b \le 0.5\,, \tag{4}$$

for non-strange heavy baryons. The corresponding two-point correlator reads:

$$S(q) = i\int d^4x\, e^{iqx}\,\langle 0|\mathcal{T}\bar{J}_{\Xi_Q}(x) J_{\Xi_Q}(0)|0\rangle \equiv \hat{q}F_1 + F_2\,, \tag{5}$$

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where F_1 and F_2 are two invariant functions.

• **For the spin 3/2 (QQq) baryons**, we also follow Ref. [6] and work with the interpolating currents:

$$J^\mu_{\Xi^*_Q} = \sqrt{\frac{1}{3}}\epsilon_{\alpha\beta\lambda}\left[2(Q^T_\alpha C\gamma^\mu d_\beta)Q_\lambda+(Q^T_\alpha C\gamma^\mu Q_\beta)q_\lambda\right] \quad (6)$$

The corresponding two-point correlator reads:

$$\begin{aligned} S^{\mu\nu}(q) &= i\int d^4x\, e^{iqx}\,\langle 0|\mathcal{T}\bar{J}^\mu_{\Xi^*_Q}(x)J^\nu_{\Xi^*_Q}(0)|0\rangle \\ &\equiv g^{\mu\nu}(\hat{q}F_1+F_2)+\ldots \end{aligned} \quad (7)$$

3. The Two-Point Correlator in QCD

The expressions of the two-point correlator using the previous interpolating currents have been obtained in the chiral limit $m_q = 0$ and including the mixed condensate contributions by [6]. In this work, we extend these results by including the linear strange quark mass corrections to the perturbative and $\langle\bar{s}s\rangle$ condensate contributions. The explicit expressions can be found in Ref. [5].

4. Form of the Sum Rules

We parametrize the spectral function using the standard duality ansatz: "one resonance"+ "QCD continuum". The QCD continuum starts from a threshold t_c and comes from the discontinuity of the QCD diagrams. Transferring its contribution to the QCD side of the sum rule, one obtains the finite energy inverse Laplace sum rules [3, 17, 18]. Consistently, we also take into account the SU(3) breaking at the continuum threshold t_c:

$$\sqrt{t_c}|_{SU(3)} \simeq \left(\sqrt{t_c}|_{SU(2)} \equiv \sqrt{t_c}\right)+\bar{m}_s\,, \quad (8)$$

where $\bar{m}_s$ is the running strange quark mass. As we do an expansion in m_s, we take the threshold $t_q = 4m_Q^2$ for consistency, where m_Q is the heavy quark mass, which we shall take in the range covered by the running and on-shell mass because of its ambiguous definition when working to lowest order (LO). As usually done in the sum rule literature, one can estimate the baryon masses from the following ratios ($i = 1,2$):

$$\mathcal{R}^q_i = \frac{\int_{t_q}^{t_c} dt\, t\, e^{-t\tau}\,\mathrm{Im}F_i(t)}{\int_{t_q}^{t_c} dt\, e^{-t\tau}\,\mathrm{Im}F_i(t)}\,, \quad \mathcal{R}^q_{21} = \frac{\int_{t_q}^{t_c} dt\, e^{-t\tau}\,\mathrm{Im}F_2(t)}{\int_{t_q}^{t_c} dt\, e^{-t\tau}\,\mathrm{Im}F_1(t)} \quad (9)$$

where at the τ-stability point :

$$M_{B_q^{(*)}} \simeq \sqrt{\mathcal{R}^q_i} \simeq \mathcal{R}^q_{21}\,, \quad (i=1,2)\,. \quad (10)$$

These predictions lead to a typical uncertainty of 10-15% [6, 7, 16], which are not competitive compared with predictions from some other approaches, especially from potential models [7, 11]. In order to improve the QSSR predictions, we work with the double ratio of sum rules (DRSR):

$$r^{sd}_i \equiv \sqrt{\frac{\mathcal{R}^s_i}{\mathcal{R}^d_i}}\,, \quad (i=1,2)\,; \qquad r^{sd}_{21} \equiv \frac{\mathcal{R}^s_{21}}{\mathcal{R}^d_{21}}\,, \quad (11)$$

which take directly into account the SU(3) breaking effects. These quantities are obviously less sensitive to the choice of the heavy quark masses and to the value of the t_c than the simple ratios $\mathcal{R}_i$ and $\mathcal{R}_{21}$.

5. The Ξ^*_{QQ}/Ξ_{QQ} mass ratio

We extract the mass ratios using the DRSR analogue of the one in Eq. (11) which we denote by:

$$r^{3/1}_i \equiv \sqrt{\frac{\mathcal{R}^3_i}{\mathcal{R}^1_i}}\,, \quad (i=1,2)\,; \qquad r^{3/1}_{21} \equiv \frac{\mathcal{R}^3_{21}}{\mathcal{R}^1_{21}}\,, \quad (12)$$

where the upper indices 3 and 1 correspond respectively to the spin 3/2 and 1/2 channels. We use the QCD expressions of the two-point correlators given by [6] which we have checked. In our analysis, we truncate the QCD series at the dimension 4 condensates until which we have calculated the m_s corrections. We shall only include the effect of the mixed condensate (if necessary) for controlling the accuracy of the approach or for improving the τ or/and t_c stability of the analysis.

• *The charm quark channel*

Fixing $t_c = 25$ GeV^2 and $\tau = 0.8$ GeV^{-2}, which are inside the t_c and τ-stability regions (see Fig. 2a and Fig. 2b), we show in Fig. 1 the b-behaviour of $r^{3/1}$ which shows that $r^{3/1}_1$ and $r^{3/1}_2$ are very stable but not $r^{3/1}_{12}$. We then eliminate $r^{3/1}_{12}$, where one can notice some common solutions for:

$$b \simeq -0.35\,, \qquad \text{and} \qquad b \simeq +0.2\,, \quad (13)$$

which are inside the range given in Eq. (4). For definiteness, we fix $b = -0.35$ and study the τ-dependence of the result in Fig. 2a and its t_c-dependence in Fig. 2b. The large stability in t_c confirms our expectation for the weak t_c-dependence of the DRSR. In these figures, we have used $m_c = 1.26$ GeV and have checked that the results are insensitive to the change of mass to $m_c = 1.47$ GeV. We have also checked that the inclusion of the mixed condensate contribution does not affect the present result (within the high-accuracy obtained here) obtained by retaining the dimension-4 condensates.