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First inverse moment of the doubly-heavy baryon distribution amplitude from HQET sum rules

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Heavy-quark symmetry (HQS), despite being approximate, allows to relate dynamically many hadron systems. In the HQS-limit doubly-heavy baryons, whose dynamics is determined by a light quark situated in a color field of a static pair of heavy quarks, are similar to heavy mesons with a heavy antiquark. Non-local interpolation currents are introduced and corresponding matrix elements between the baryon and vacuum state are expressed in terms of light-cone distribution amplitudes. As well known, the first inverse moment of the leading twist B-meson distribution amplitude (DA) is a very important hadronic parameter needed for an accurate theoretical description of B-meson exclusive decays. It is quite natural that a similar moment of doubly-heavy baryons is of importance in exclusive doubly-heavy baryons' decays. We obtain HQET sum rules for the first inverse moment based on the correlation functions containing nonlocal heavy-light operators of doubly-heavy baryons and their local interpolating currents.

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Doubly heavy baryons (DHBs) are strongly-coupled systems consisting of two heavy c- or b-quarks and one light u-, d- or s-quark. They are denoted according their isospin and heavy quark content. The isospin-1/2 DHBs are naming as $\Xi_{cc}(ccq)$, $\Xi_{bc}(bcq)$ and $\Xi_{bb}(bbq)$, where $q = u,\, d$, while the strange DHBs, $\Omega_{cc}(ccs)$, $\Omega_{cb}(cbs)$ and $\Omega_{bb}(bbs)$, have no the isospin. For a long time, DHBs were a matter of intense searches until 2017 when one of them, $\Xi_{cc}^{++}(ccu)$, was observed by LHCb Collaboration in the $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^-$ decay [1] and confirmed in the $\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$ mode [2]. Its experimental mass and width are $M_{\Xi_{cc}^{++}} = (3621.6 \pm 0.4)$ MeV and $\Gamma_{\Xi_{cc}^{++}} = (2.56 \pm 0.27) \times 10^{-13}$ s [3]. An existence of its isospin partner Ξ_{cc}^+ still remains controversial and experimental observation of this state is one of the main goal of the LHCb in the decays $\Xi_{cc}^+ \to \Lambda_c^+ K^- \pi^+$ [4] $\Xi_{cc}^+ \to \Xi_c^+ \pi^- \pi^+$ [5] with the present combined global significance of 2.9 standard deviations including systematic uncertainties.

Theoretically, doubly heavy baryon is dynamically similar to a heavy meson. Dynamics of both is determined by a light quark being in the color external field of the heavy antiquark in the heavy meson or doubly heavy diquark in DHB. Assuming that heavy constituents of both hadrons are point-like static sources, one can extend the light-cone approach to the heavy-meson wave-function [6, 7] onto the DHB wave-function. Let these heavy constituents are situated at the origin of the frame (the frame for the heavy meson is presented in Fig. 1) in which one can introduce the light cone determined by two light-like vectors $n_\pm^\mu = (1, 0, 0, \mp 1)\,/\sqrt{2}\; (n_\pm^2 = 0$ and $(n_+ n_-) = 1)$, so that an arbitrary four-vector has the following decomposition: $V^\mu = V_+ n_-^\mu + V_- n_+^\mu + V_\perp^\mu$, where $V_\pm = n_\pm^\mu V_\mu$. In this picture, the heavy antiquark or doubly heavy diquark are connected with the light quark by the Wilson line $E(0, z)$ which takes the value $E(0, z) = 1$ in the Fock-Schwinger gauge of the gluonic field, $A_+(z) = 0$.

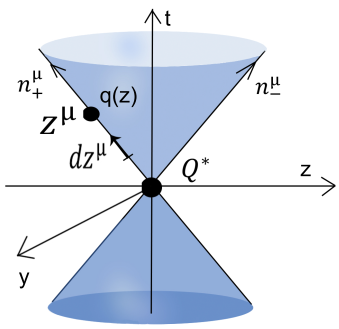

Figure 1: B-meson representation in the heavy-quark rest frame. The light quark $q(z)$ is on the light cone.

In this paper, we consider the B-meson as a heavy meson and exemplify doubly heavy baryons by Ξ_{bc}. For the Ω_{bc}-baryon, the s-quark mass should be included into consideration but mass corrections are not discussed here. The matrix element of the B-meson axial-vector current has the form $\langle 0 \mid \bar{b}(0)\gamma^\mu\gamma_5 q(0) \mid B(p_B)\rangle = i f_B p_B^\mu$, where $q(x)$ and $b(x)$ are the light and heavy quark fields, p_B^μ is the four-momentum of the B-meson, and $f_B \simeq 190$ MeV is the B-meson decay constant. General structure of the Ξ_{bc}-baryon current is as follows: $J_{\Xi_{bc}}(x) = \epsilon_{\alpha\beta\gamma}\left[b(x)^{\alpha T} C\gamma_5 c(x)^\beta\right]\Gamma' q(x)^\gamma$, where α, β, and γ are color indices, $\Gamma^{(\prime)} = \left\{I, \gamma_5, \gamma_\mu, \gamma_\mu\gamma_5, \sigma_{\mu\nu} = i[\gamma_\mu, \gamma_\nu]/2\right\}$, and C is the charged conjugation matrix. The transition matrix element from Ξ_{bc} state with $J^P = 1/2^+$ to the vacuum one can be written as $\langle 0|J_{\Xi_{bc}}(0)|\Xi_{bc}(v)\rangle = i\, f_{\Xi_{bc}}\, U(v)$, where $U(v)$ is the spin-1/2 baryon bispinor. For the baryon with the spin-parity $J^P = 3/2^+$, the bispinor $U(v)$ should be replaced by a vector-spinor $U^\mu(v)$.

The matrix element of the non-local current can be obtained in a similar way as it was done for the heavy B-meson [6]. In the heavy meson, an antiquark Q^* is infinitely heavy and, hence, static while a light quark q is separated by a distance z from it ($z^2 = 0$) and determines a hadron dynamics (see Fig. 1). In the baryon considered a light quark is at a distance z from the center of the doubly heavy diquark:

$$\tilde{O}_0(t) = d(0)\, q(z), \qquad \tilde{O}_1^{\mu}(t) = \varepsilon^{\mu}(0)\, q(z), \tag{1}$$

where $d(0)$ and $\varepsilon^{\mu}(0)$ are spin $S = 0$ or $S = 1$ doubly heavy diquarks QQ', being at rest, $t = (vz)$, and the Wilson line $E(0, z)$ is suppressed. For the Ξ_{bc}-baryon, the spinless diquark is assumed, vector diquark is not considered here. Because of the heavy-quark symmetry, there are two Light-Cone Distribution Amplitudes (LCDAs) only entering the heavy meson wave-function [6]. The same is true for the Ξ_{bc}-baryon and two LCDAs $\tilde{\varphi}_+(t)$ and $\tilde{\varphi}_-(t)$ are introduced:

$$\left\langle 0 \left| \tilde{O}_0(t) \right| \Xi_{bc} \right\rangle = i f_{\Xi_{bc}} \left\{ \tilde{\varphi}_+ + [\tilde{\varphi}_- - \tilde{\varphi}_+] \frac{\hat{z}}{2t} \right\} U(v). \tag{2}$$

In general, doubly heavy diquarks should be considered as states formed by two heavy quarks which are spatially separated by a distance R. To form sum rules, one should use local currents in which both heavy quarks are situated in the same point. This means that diquark is a local object.

In QCD Sum Rules (QCD-SRs), one starts from a vacuum average of two or more currents [6] like local and non-local interpolation currents of the Ξ_{bc}-baryon: $\left\langle 0 \left| \tilde{O}^{\Xi_{bc}}(t)\, J_{\Xi_{bc}}(-x) \right| \Xi_{bc} \right\rangle$. The procedure of transforming this matrix element into the QCD Sum Rules is the same as for the B-meson [6]. Following the same steps, we arrive to the sum rules for the leading twist LCDA $\varphi_+(\omega)$ which is the Fourier transform of the position-space $\tilde{\varphi}_+(t)$:

$$f_{\Xi_{bc}}^2 \varphi_+(\omega) = \frac{3\omega}{8\pi^2 \tau}\, e^{(\bar{\Lambda} - \omega/2)\tau} \left[1 - e^{-(\varepsilon_c - \omega/2)\tau} \right] - \frac{<\bar{q}q>}{8\tau}\, \tilde{f}_S \left(\frac{\omega}{2\tau} \right) e^{(\bar{\Lambda} - \omega/2)\tau}, \tag{3}$$

where $\bar{\Lambda} = M_{\Xi_{bc}} - m_b - m_c$ is the effective baryon mass, m_b and m_c are the b- and c-quark masses, $<\bar{q}q>$ is the local condensate of light quarks, τ is the Borel parameter, ε_c is an effective QCD-SRs threshold. The function $\tilde{f}_S\,(\nu)$, being a shape of a non-local quark condensate, is related with $f_S\left(x^2\right)$ as $f_S\left(x^2\right) = \int d\nu\, \tilde{f}_S\,(\nu)\; e^{\nu x^2}$ [6]. For $\tilde{f}_S\,(\nu)$, there are two models [8, 9]:

$$\tilde{f}_S^{\mathrm{I}}\,(\nu) = \delta\left(\nu - m_0^2/4\right), \qquad \tilde{f}_S^{\mathrm{II}}\,(\nu) = \frac{\lambda^{p-2}}{\Gamma(p-2)}\, \nu^{1-p}\, e^{-\lambda/\nu}, \tag{4}$$

where $p = 3 + 4\lambda/m_0^2$, $m_0^2 = \langle \bar{q}\sigma_{\mu\nu}G^{\mu\nu}q\rangle / \langle \bar{q}q \rangle$ is the quantity entering the quark-gluon condensate, and λ is a free parameter.

As in the case of heavy mesons, the first inverse moment of the leading-twist LCDA:

$$\lambda_{\Xi_{bc}}^{-1} = \int_0^{\infty} \frac{d\omega}{\omega}\, \varphi_+(\omega), \tag{5}$$

is of interest in physical applications where a doubly heavy baryon is involved. To get these sum rules, one needs to integrate out the sum rules for $\varphi_+(\omega)$ with the $1/\omega$ weight factor. Such sum rules for the $B_{(s)}$-meson were derived in [10]. The analytical form of these sum rules obtained for the Ξ_{bc}-baryon to leading order in α_{st} for the second type of the non-local quark condensate is as follows:

$$\lambda_{\Xi_{bc}}^{-1} = \frac{e^{\bar{\Lambda}\tau}}{4\pi^2 f_{\Xi_{bc}}^2} \left[1 - \frac{\pi^2 <\bar{q}q>}{\tau\,\Gamma(p-2)}\, \lambda^{(p-3)/2} K_{p-1}(2\sqrt{\lambda}) \right], \tag{6}$$

where $K_\nu(z)$ is the modified Bessel function. One can also obtain s-quark corrections when apply this analysis to the strange Ω_{bc}-baryon, similar to the B_s-meson [10]. Numerical results and details of the analysis can be found in the forthcoming paper.

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The Heavy-Quark Symmetry was applied to the construction of LCDAs of doubly-heavy baryons on the light cone. Dynamically, these LCDAs are similar to the ones in the heavy meson as both are determined by a motion of one light quark. There are two LCDAs in the doubly-heavy baryon of which $\varphi_+(\omega)$ is the leading twist one. Sum Rules for the calculation of its first inverse moment are discussed.

References

[1] LHCb collaboration, *Observation of the doubly charmed baryon* Ξ_{cc}^{++}, *Phys. Rev. Lett.* **119** (2017) 112001 [1707.01621].

[2] LHCb collaboration, *First Observation of the Doubly Charmed Baryon Decay* $\Xi_{cc}^{++} \to \Xi_c^+\pi^+$, *Phys. Rev. Lett.* **121** (2018) 162002 [1807.01919].

[3] Particle Data Group collaboration, *Review of Particle Physics*, *PTEP* **2020** (2020) 083C01.

[4] LHCb collaboration, *Search for the doubly charmed baryon* Ξ_{cc}^{+}, *Sci. China Phys. Mech. Astron.* **63** (2020) 221062 [1909.12273].

[5] LHCb collaboration, *Search for the doubly charmed baryon* Ξ_{cc}^{+} *in the* $\Xi_c^+\pi^-\pi^+$ *final state*, 2109.07292.

[6] A. Grozin and M. Neubert, *Asymptotics of heavy meson form-factors*, *Phys. Rev. D* **55** (1997) 272 [hep-ph/9607366].

[7] A. G. Grozin, *B-meson distribution amplitudes*, *Int. J. Mod. Phys. A* **20** (2005) 7451 [hep-ph/0506226].

[8] S. V. Mikhailov and A. V. Radyushkin, *The pion wave-function and QCD sum rules with nonlocal condensates*, *Phys. Rev. D* **45** (1992) 1754.

[9] V. Braun, P. Gornicki and L. Mankiewicz, *Ioffe-time distributions instead of parton momentum distributions in description of deep inelastic scattering*, *Phys. Rev. D* **51** (1995) 6036 [hep-ph/9410318].

[10] A. Khodjamirian, R. Mandal and T. Mannel, *Inverse moment of the* B_s*-meson distribution amplitude from QCD sum rule*, *JHEP* **10** (2020) 043 [2008.03935].

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