String point of view for heavy-light mesons (postprint)

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Date: 2017-11-10T00:00:00+00:00

Abstract

An approximate rotational symmetry of a heavy-light meson is viewed from a string picture. Using a simple string configuration, we derive a formula, (M−mc)2 = L, whose coefficient of the r.h.s. is just 1/2 of that of a light meson with two light quarks. A numerical plot is obtained for Dmesons of experimental data as well as several theoretical models, which shows good agreement with this formula.

Full Text

String Point of View for Heavy-Light Mesons

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Abstract

An approximate rotational symmetry of a heavy-light meson is viewed from a string picture. Using a simple string configuration, we derive a formula, $(M -$

$m_c)^2 = \pi\sigma L$, whose coefficient on the right-hand side is just one half of that for a light meson with two light quarks. A numerical plot is obtained for D mesons from experimental data as well as several theoretical models, which shows good agreement with this formula.

1 Observation of Experimental Spectra

In our previous paper [1], we pointed out that careful observation of the experimental spectra of heavy-light mesons reveals that heavy-light mesons with the same angular momentum L are almost degenerate. Mass differences within a heavy quark spin doublet and between doublets with the same L are very small compared to the mass gap between different multiplets with different L, which is nearly equal to the value of $\Lambda_{\rm QCD} \sim 300$ MeV. In this report, we present a different perspective on heavy-light mesons using the framework of hadronic open strings. With this picture, we can intuitively and physically understand why the masses of heavy-light mesons are proportional to L.

2 Mass and Angular Momentum

We adopt Nambu's picture [2] of a hadronic string, which consists only of gluons with quarks attached at both ends in the case of mesons. Afonin cited Nambu's paper to derive the Chew-Frautsch formula:

$$M^2 = 2\pi\sigma L. \tag{1}$$

Afonin's derivation proceeds as follows [3]; see also Refs. [4, 5] for other applications. Assuming a simple string configuration, we obtain the mass M and angular momentum L given by

$$M = 2\int_0^{\ell/2} \frac{\sigma r}{\sqrt{1-v^2(r)}}\, dr, \tag{2}$$

$$L = 2\int_0^{\ell/2} \frac{\sigma r v^2(r)}{\sqrt{1-v^2(r)}}\, dr, \tag{3}$$

where σ is the string tension, ℓ is the length of a string connecting two light quarks at the ends, and $v(r) = 2r/\ell$ is the speed of the flux tube at distance r from the center of rotation. Equations (2) and (3) are obtained by assuming the simplest configuration of a string connecting two quarks at both ends moving at the speed of light c and rotating about the center-of-mass system. Combining these two equations yields Eq. (1).

Let us apply this idea to a heavy-light meson. In the heavy quark limit, we consider the situation where a heavy quark is fixed at one end while a light quark rotates around it at the speed of light c, as depicted in Fig. 1 [Figure 1: see original paper]. This yields the relation:

$$M^2 = \pi\sigma L. \tag{4}$$

The right-hand side of this equation is exactly half of Eq. (1), but our numerical plot does not fit this equation. Since Nambu' s string consists only of gluons, we must remove the effects of quark masses. In our case, within the heavy quark effective theory limit, we subtract only the charm quark mass from M. Hence, the final expression we adopt is

$$(M - m_c)^2 = \pi\sigma L. \tag{5}$$

Figure 1 [Figure 1: see original paper] (color online) shows a schematic diagram of the string connecting heavy and light quarks at its ends and rotating about the heavy quark. The heavy quark is fixed at a point.

Based on Eq. (5), we plot figures for D and B mesons using experimental data [6] as well as model calculations from Godfrey and Isgur [7], shown in Figs. 2 and 3. To compare Eq. (1) with Eq. (5), we provide the numerical coefficient of L in Eq. (1) obtained by Afonin:

$$M^2 = 1.103L + \cdots, \tag{6}$$

which is taken from Table 4 of Ref. [3].

In summary, examining Figs. 2 and 3 together with the linear equations written on the figures, we conclude that the string picture for heavy-light mesons works well and supports the approximate rotational symmetry of heavy-light mesons claimed in our previous paper [1].

Figure 2 [Figure 2: see original paper] (color online). Plots of experimental data: L versus $(M - m_{c,b})^2$. The best-fit lines are shown with their equations.

Figure 3 [Figure 3: see original paper] (color online). Plots of values from the Godfrey-Isgur model, similar to Fig. 2. The best-fit lines are shown with their equations.

Acknowledgements

This work is partly supported by the National Natural Science Foundation of China under Grant No. 11475192, and in part by the DFG and the NSFC through funds provided to the Sino-German CRC 110 "Symmetries and the Emergence of Structure in QCD" . This work is also supported by the China Postdoctoral Science Foundation under Grant No. 2016M601133. T. Matsuki wishes to thank Yubing Dong for his kind hospitality at IHEP, Beijing, where part of this work was carried out.

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Note: Figure translations are in progress. See original paper for figures.