# A note on $\Xi_c(3055)^+$ and $\Xi_c(3123)^+$ *

LIU Xiang(刘翔)[1)] CHEN Chong(陈冲) DENG Wei-Zhen(邓卫真) CHEN Xiao-Lin(陈晓林)[2)]

(Department of Physics, Peking University, Beijing 100871, China)

**Abstract** The Babar Collaboration announced two new excited charmed baryons $\Xi_c(3055)^+$ and $\Xi_c(3123)^+$. We study their strong decays assuming they are $D$-wave states. Some assignments are excluded by comparing our numerical results with the experimental values of the total widths of $\Xi_c(3055)^+$ and $\Xi_c(3123)^+$. We also suggest some possible decay modes, which will be helpful to determine the properties of $\Xi_c(3055)^+$ and $\Xi_c(3123)^+$.

**Key words** $^3P_0$ model, charmed baryon, strong decay

**PACS** 13.30.Eg, 12.39.Jh

At the recent 2007 Euro-physics Conference on High Energy Physics, Babar Collaboration reported the preliminary results about the observations of two new excited charmed baryons $\Xi_c(3055)^+$ and $\Xi_c(3123)^+$ in the mass distribution of $\Lambda_c^+K^-\pi^+$[1]. Besides these new observations, Babar also confirmed the observation of $\Xi_c(2980)^+$ and $\Xi_c(3077)^+$[2, 3]. The masses and widths of $\Xi_c(3055)^+$ and $\Xi_c(3123)^+$ are

$$m_{\Xi_c(3055)^+} = 3054.2\pm1.2\pm0.5\,\mathrm{MeV}/c^2,$$
$$\Gamma_{\Xi_c(3055)^+} = 17\pm6\pm11\,\mathrm{MeV}/c^2,$$
$$m_{\Xi_c(3123)^+} = 3122.9\pm1.3\pm0.3\,\mathrm{MeV}/c^2,$$
$$\Gamma_{\Xi_c(3123)^+} = 4.4\pm3.4\pm1.7\,\mathrm{MeV}/c^2.$$

In order to understand the recently observed $\Lambda_c(2880,2940)^+$, $\Xi_c(2980,3077)^{+,0}$, and $\Omega_c(2768)^0$[2—6], we studied the strong decays of the $S$-wave, $P$-wave, $D$-wave, and radially excited charmed baryons using the $^3P_0$ model systemically[7]. (For more details of the $^3P_0$ model, see Refs. [8—19]).

In this short note, we analyze the strong decays of $\Xi_c(3055)^+$ and $\Xi_c(3123)^+$ using the same formalism as in Ref. [7], which will be helpful to determine the quantum number of $\Xi_c(3055)^+$ and $\Xi_c(3123)^+$. Because the parity of these states is even, they are either the first radial excitation or $D$-wave charmed baryons. In our previous work[7], we studied the total decay width of $\Xi_c(3077)^+$ assuming it's a candidate of the first radial excitation. Because their masses are close, the decay pattern of $\Xi_c(3055,3123)^+$ should be similar to that presented in Ref. [7] if either of them is the radial excitation. In this work, we will not discuss the assignment for $\Xi_c(3055,3123)^+$ (Interested reader can consult Ref. [7]). In the following, we estimate their strong decays if $\Xi_c(3055)^+$ and $\Xi_c(3123)^+$ are candidates of $D$-wave states. We list the spectrum of $D$-wave excited spectrum in Fig. 1. We omit the detailed expressions of the strong decays of $D$-wave charmed baryons derived by this model. Interested readers may consult our former paper[7] for details.

The decay widths of charmed baryons from the $^3P_0$ model involve several parameters: the strength of quark pair creation from vacuum $\gamma$, the $R$ value in the harmonic oscillator wave function of meson and the $\alpha_{\rho,\lambda}$ in the baryon wave functions. We follow the convention of Ref. [20] and take $\gamma = 13.4$, which is considered as a universal parameter in the $^3P_0$ model. The $R$ value of $\pi$ and K mesons is 2.1 $\mathrm{GeV}^{-1}$[20] while it's $R$=2.3 $\mathrm{GeV}^{-1}$ for the D meson[21]. $\alpha_\rho = \alpha_\lambda$=0.5 GeV for the proton and $\Lambda$[19]. For $S$-wave charmed baryons, the parameters $\alpha_\rho$ and $\alpha_\lambda$ in the harmonic oscillator wave functions can be fixed to reproduce the mass splitting through the contact term in the potential model[22]. Their values are $\alpha_\rho$=0.6 GeV and $\alpha_\lambda$=0.6 GeV. For $P$-wave and $D$-wave charmed baryons, $\alpha_\rho$ and $\alpha_\lambda$ are expected to

Received 24 September 2007

* Supported by National Natural Science Foundation of China (10421503, 10625521, 10705001) and China Postdoctoral Science Foundation (20060400376)

1) E-mail: xiangliu@pku.edu.cn

2) E-mail: xlchen@th.phy.pku.edu.cn

lie in the range 0.5—0.7 GeV. In the following, our numerical results are obtained with the typical values $\alpha_\rho=\alpha_\lambda$=0.6 GeV. In the following, we listed the numerical results of the strong decays of $\Xi_c(3055)^+$ and $\Xi_c(3123)^+$ in Tables 1, 2.

At present only total widths of $\Xi_c(3055,3123)^+$ are measured experimentally. Through comparing our numerical results with experimental values, we exclude some $D$-wave assignments for $\Xi_c(3055,3123)^+$, which are marked by "×" in Tables 1, 2. In order to fully determine the quantum numbers of $\Xi_c(3055,3123)^+$, we suggest:

Table 1. The decay widths of $\Xi_c^+(3055)$ with different $D$-wave assignments. Here we list the results with the typical values $\alpha_\rho$=0.6 GeV and $\alpha_\lambda$=0.6 GeV.

| assignment | $\Xi_c^0\pi^+$ | $\Xi_c'^0\pi^+$ | $\Xi_c^{*0}\pi^+$ | $\Sigma_c^{++}k^-$ | $\Sigma_c^{*++}k^-$ | $\Lambda_c^+\bar{k}^0$ | $D^+\Lambda$ | remark |
|---|---|---|---|---|---|---|---|---|
| $\Xi_{c2}\left(\frac{3}{2}^+\right)$ | 0.0 | 1.9 | 0.25 | 2.2 | 0.12 | 0.0 | 0.0 | |
| $\Xi_{c2}\left(\frac{5}{2}^+\right)$ | 0.0 | 0.028 | 1.4 | $0.83\times10^{-2}$ | 0.69 | 0.0 | 0.0 | |
| $\Xi'_{c1}\left(\frac{1}{2}^+\right)$ | 6.4 | 1.3 | 0.38 | 1.5 | 0.19 | 8.0 | 2.4 | |
| $\Xi'_{c1}\left(\frac{3}{2}^+\right)$ | 6.4 | 0.32 | 0.96 | 0.37 | 0.48 | 8.0 | 2.4 | |
| $\Xi'_{c2}\left(\frac{3}{2}^+\right)$ | 0.0 | 2.9 | 0.36 | 3.3 | 0.17 | 0.0 | 0.0 | |
| $\Xi'_{c2}\left(\frac{5}{2}^+\right)$ | 0.0 | 0.019 | 2.1 | $0.55\times10^{-2}$ | 1.0 | 0.0 | 0.0 | |
| $\Xi'_{c3}\left(\frac{5}{2}^+\right)$ | 0.15 | 0.022 | $0.78\times10^{-2}$ | $0.63\times10^{-2}$ | $0.30\times10^{-3}$ | 0.18 | 0.0067 | × |
| $\Xi'_{c3}\left(\frac{7}{2}^+\right)$ | 0.15 | 0.012 | 0.011 | $0.35\times10^{-2}$ | $0.41\times10^{-3}$ | 0.18 | 0.0067 | × |
| $\hat{\Xi}_{c2}\left(\frac{3}{2}^+\right)$ | 0.0 | 27.4 | 21.3 | 14.4 | 2.5 | 0.0 | 0.0 | × |
| $\hat{\Xi}_{c2}\left(\frac{5}{2}^+\right)$ | 0.0 | 27.4 | 21.3 | 14.4 | 2.5 | 0.0 | 0.0 | × |
| $\hat{\Xi}'_{c1}\left(\frac{1}{2}^+\right)$ | 163 | 18.3 | 3.5 | 9.6 | 0.41 | 205 | 15.5 | × |
| $\hat{\Xi}'_{c1}\left(\frac{3}{2}^+\right)$ | 163 | 4.6 | 8.9 | 2.4 | 1.0 | 205 | 15.5 | × |
| $\hat{\Xi}'_{c2}\left(\frac{3}{2}^+\right)$ | 0.0 | 41.1 | 15.9 | 21.5 | 1.9 | 0.0 | 0.0 | × |
| $\hat{\Xi}'_{c2}\left(\frac{5}{2}^+\right)$ | 0.0 | 18.3 | 24.8 | 9.6 | 2.9 | 0.0 | 0.0 | × |
| $\hat{\Xi}'_{c3}\left(\frac{5}{2}^+\right)$ | 105 | 20.9 | 10.1 | 10.9 | 1.2 | 131 | 10.0 | × |
| $\hat{\Xi}'_{c3}\left(\frac{7}{2}^+\right)$ | 105 | 11.7 | 13.7 | 6.1 | 1.6 | 131 | 10.0 | × |
| $\check{\Xi}'^0_{c0}\left(\frac{1}{2}^+\right)$ | 0.0 | 0.23 | 0.46 | 1.9 | 2.9 | 0.0 | 0.0 | |
| $\check{\Xi}^0_{c1}\left(\frac{1}{2}^+\right)$ | 9.8 | 0.30 | 0.15 | 2.6 | 0.95 | 12.4 | 0.60 | |
| $\check{\Xi}^0_{c1}\left(\frac{3}{2}^+\right)$ | 9.8 | 0.075 | 0.38 | 0.65 | 2.4 | 12.4 | 0.60 | |
| $\check{\Xi}'^1_{c1}\left(\frac{1}{2}^+\right)$ | 0.0 | 34.7 | 9.8 | 36.0 | 4.1 | 0.0 | 0.0 | × |
| $\check{\Xi}'^1_{c1}\left(\frac{3}{2}^+\right)$ | 0.0 | 8.7 | 24.4 | 9.0 | 10.3 | 0.0 | 0.0 | × |
| $\check{\Xi}^1_{c0}\left(\frac{1}{2}^+\right)$ | 0.0 | 34.7 | 39.1 | 36.0 | 16.6 | 0.0 | 0.0 | × |
| $\check{\Xi}^1_{c1}\left(\frac{1}{2}^+\right)$ | 97.6 | 17.4 | 4.9 | 18.0 | 2.1 | 122 | 28.2 | × |
| $\check{\Xi}^1_{c1}\left(\frac{3}{2}^+\right)$ | 97.6 | 4.3 | 12.2 | 4.5 | 5.2 | 122 | 28.2 | × |
| $\check{\Xi}^1_{c2}\left(\frac{3}{2}^+\right)$ | 0.0 | 21.7 | 2.4 | 22.5 | 1.0 | 0.0 | 0.0 | × |
| $\check{\Xi}^1_{c2}\left(\frac{5}{2}^+\right)$ | 0.0 | 0.0 | 14.7 | 0.0 | 6.2 | 0.0 | 0.0 | |
| $\check{\Xi}'^2_{c2}\left(\frac{3}{2}^+\right)$ | 0.0 | 8.6 | 4.7 | 12.3 | 1.5 | 0.0 | 0.0 | |
| $\check{\Xi}'^2_{c2}\left(\frac{5}{2}^+\right)$ | 0.0 | 4.7 | 8.7 | 2.8 | 4.4 | 0.0 | 0.0 | |
| $\check{\Xi}^2_{c1}\left(\frac{1}{2}^+\right)$ | 21.9 | 5.7 | 2.0 | 8.2 | 1.1 | 27.2 | 12.2 | × |
| $\check{\Xi}^2_{c1}\left(\frac{3}{2}^+\right)$ | 21.9 | 1.4 | 4.9 | 2.1 | 2.8 | 27.2 | 12.2 | × |
| $\check{\Xi}^2_{c2}\left(\frac{3}{2}^+\right)$ | 0.0 | 12.9 | 4.1 | 18.5 | 1.5 | 0.0 | 0.0 | × |
| $\check{\Xi}^2_{c2}\left(\frac{5}{2}^+\right)$ | 0.0 | 3.2 | 11.7 | 1.9 | 6.3 | 0.0 | 0.0 | |
| $\check{\Xi}^2_{c3}\left(\frac{5}{2}^+\right)$ | 17.4 | 3.6 | 1.9 | 2.2 | 0.41 | 21.9 | 2.1 | × |
| $\check{\Xi}^2_{c3}\left(\frac{7}{2}^+\right)$ | 17.4 | 2.0 | 2.5 | 1.2 | 0.57 | 21.9 | 2.1 | × |

Table 2. The decay widths of $\Xi_c^+(3123)$ with different $D$-wave assignments. Here we list the results with the typical values $\alpha_\rho$=0.6 GeV and $\alpha_\lambda$=0.6 GeV.

| assignment | $\Xi_c^0\pi^+$ | $\Xi_c'^0\pi^+$ | $\Xi_c^{*0}\pi^+$ | $\Sigma_c^{++}k^-$ | $\Sigma_c^{*++}k^-$ | $\Lambda_c^+\bar{k}^0$ | $D^+\Lambda$ | remark |
|---|---|---|---|---|---|---|---|---|
| $\Xi_{c2}\left(\frac{3}{2}^+\right)$ | 0.0 | 2.8 | 0.43 | 4.5 | 0.49 | 0.0 | 0.0 | |
| $\Xi_{c2}\left(\frac{5}{2}^+\right)$ | 0.0 | 0.075 | 2.3 | 0.053 | 2.8 | 0.0 | 0.0 | |
| $\Xi'_{c1}\left(\frac{1}{2}^+\right)$ | 8.3 | 1.9 | 0.63 | 3.0 | 0.79 | 10.2 | 5.5 | × |
| $\Xi'_{c1}\left(\frac{3}{2}^+\right)$ | 8.3 | 0.46 | 1.6 | 0.76 | 2.0 | 10.2 | 5.5 | × |
| $\Xi'_{c2}\left(\frac{3}{2}^+\right)$ | 0.0 | 4.2 | 0.60 | 6.8 | 0.72 | 0.0 | 0.0 | |
| $\Xi'_{c2}\left(\frac{5}{2}^+\right)$ | 0.0 | 0.050 | 3.4 | 0.035 | 4.3 | 0.0 | 0.0 | |
| $\Xi'_{c3}\left(\frac{5}{2}^+\right)$ | 0.32 | 0.057 | 0.026 | 0.040 | 0.010 | 0.44 | 0.069 | × |
| $\Xi'_{c3}\left(\frac{7}{2}^+\right)$ | 0.32 | 0.032 | 0.035 | 0.023 | 0.013 | 0.44 | 0.069 | × |
| $\hat{\Xi}_{c2}\left(\frac{3}{2}^+\right)$ | 0.0 | 58.9 | 53.0 | 56.0 | 30.0 | 0.0 | 0.0 | × |
| $\hat{\Xi}_{c2}\left(\frac{5}{2}^+\right)$ | 0.0 | 58.9 | 53.0 | 56.0 | 30.0 | 0.0 | 0.0 | × |
| $\hat{\Xi}'_{c1}\left(\frac{1}{2}^+\right)$ | 311 | 39.2 | 8.8 | 37.4 | 5.0 | 411 | 85.9 | × |
| $\hat{\Xi}'_{c1}\left(\frac{3}{2}^+\right)$ | 311 | 9.8 | 22.1 | 9.3 | 12.5 | 411 | 85.9 | × |
| $\hat{\Xi}'_{c2}\left(\frac{3}{2}^+\right)$ | 0.0 | 88.3 | 40.0 | 84.1 | 22.5 | 0.0 | 0.0 | × |
| $\hat{\Xi}'_{c2}\left(\frac{5}{2}^+\right)$ | 0.0 | 39.2 | 61.8 | 37.4 | 35.0 | 0.0 | 0.0 | × |
| $\hat{\Xi}'_{c3}\left(\frac{5}{2}^+\right)$ | 200 | 44.8 | 25.2 | 42.7 | 14.3 | 264 | 55.3 | × |
| $\hat{\Xi}'_{c3}\left(\frac{7}{2}^+\right)$ | 200 | 25.2 | 34.0 | 24.0 | 19.3 | 264 | 55.3 | × |
| $\check{\Xi}'^0_{c0}\left(\frac{1}{2}^+\right)$ | 0.0 | 4.3 | 0.35 | 0.015 | 2.5 | 0.0 | 0.0 | |
| $\check{\Xi}^0_{c1}\left(\frac{1}{2}^+\right)$ | 36.5 | 5.8 | 0.12 | 0.020 | 0.82 | 52.7 | 1.8 | × |
| $\check{\Xi}^0_{c1}\left(\frac{3}{2}^+\right)$ | 36.5 | 1.4 | 0.29 | 0.005 | 2.0 | 52.7 | 1.8 | × |
| $\check{\Xi}'^1_{c1}\left(\frac{1}{2}^+\right)$ | 0.0 | 54.3 | 17.0 | 80.2 | 18.3 | 0.0 | 0.0 | × |
| $\check{\Xi}'^1_{c1}\left(\frac{3}{2}^+\right)$ | 0.0 | 13.6 | 42.6 | 20.1 | 45.8 | 0.0 | 0.0 | × |
| $\check{\Xi}^1_{c0}\left(\frac{1}{2}^+\right)$ | 0.0 | 54.3 | 68.2 | 80.2 | 73.3 | 0.0 | 0.0 | × |
| $\check{\Xi}^1_{c1}\left(\frac{1}{2}^+\right)$ | 139 | 27.1 | 8.5 | 40.1 | 9.2 | 175 | 73.3 | × |
| $\check{\Xi}^1_{c1}\left(\frac{3}{2}^+\right)$ | 139 | 6.8 | 21.3 | 10.0 | 22.9 | 175 | 73.3 | × |
| $\check{\Xi}^1_{c2}\left(\frac{3}{2}^+\right)$ | 0.0 | 33.9 | 4.3 | 50.1 | 4.6 | 0.0 | 0.0 | × |
| $\check{\Xi}^1_{c2}\left(\frac{5}{2}^+\right)$ | 0.0 | 0.0 | 25.6 | 0.0 | 27.5 | 0.0 | 0.0 | × |
| $\check{\Xi}'^2_{c2}\left(\frac{3}{2}^+\right)$ | 0.0 | 10.5 | 10.0 | 21.3 | 8.1 | 0.0 | 0.0 | × |
| $\check{\Xi}'^2_{c2}\left(\frac{5}{2}^+\right)$ | 0.0 | 9.9 | 13.9 | 9.8 | 16.9 | 0.0 | 0.0 | × |
| $\check{\Xi}^2_{c1}\left(\frac{1}{2}^+\right)$ | 21.6 | 7.0 | 2.8 | 14.2 | 4.0 | 25.2 | 21.1 | × |
| $\check{\Xi}^2_{c1}\left(\frac{3}{2}^+\right)$ | 21.6 | 1.7 | 7.1 | 3.6 | 10.0 | 25.2 | 21.1 | × |
| $\check{\Xi}^2_{c2}\left(\frac{3}{2}^+\right)$ | 0.0 | 15.7 | 8.1 | 32.0 | 7.4 | 0.0 | 0.0 | × |
| $\check{\Xi}^2_{c2}\left(\frac{5}{2}^+\right)$ | 0.0 | 6.6 | 17.7 | 6.6 | 23.2 | 0.0 | 0.0 | × |
| $\check{\Xi}^2_{c3}\left(\frac{5}{2}^+\right)$ | 32.7 | 7.5 | 4.4 | 7.5 | 3.0 | 43.1 | 10.1 | × |
| $\check{\Xi}^2_{c3}\left(\frac{7}{2}^+\right)$ | 32.7 | 4.2 | 5.9 | 4.2 | 4.1 | 43.1 | 10.1 | × |

1) Search for other possible decay modes of $\Xi_c(3055,3123)^+$. From Tables 1, 2, one notes that some decay modes are forbidden for $\Xi_c(3055,3123)^+$ with several assignments of their quantum numbers, which provides some useful hint for exclusion or confirmation of certain $J^P$.

2) Measure the ratio between different decay modes $\Xi_c^0\pi^+ : \Xi'_c(0)\pi^+ : \Xi_c^{*0}\pi^+ : \Sigma_c^{++}K^- : \Sigma_c^{*++}K^- : \Lambda_c^+K^0 : D^+\Lambda$. Our numerical results show this ratio is different for the different assignment.

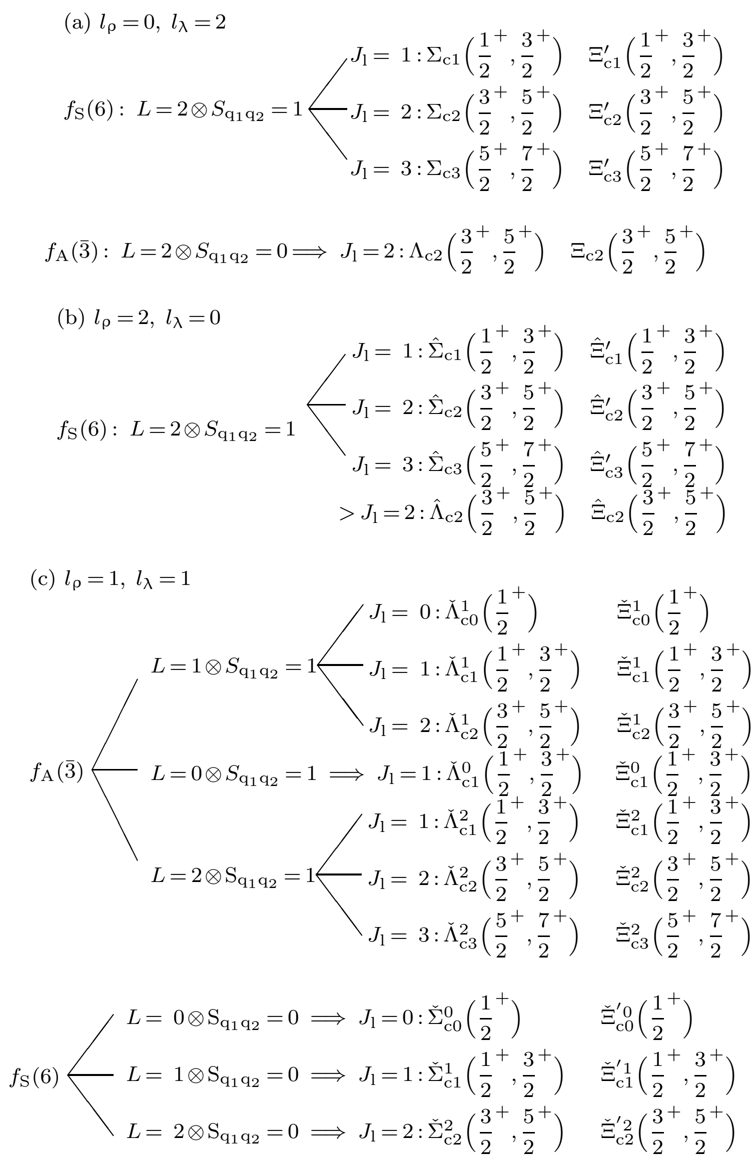


Fig. 1. The notations for the $D$-wave charmed baryons.

## References


1 Schröder T (Babar Collaboration). Talk given at the EPS High Energy Physics Conference, Manchester, July, 2007
2 Aubert B et al (BABAR Collaboration). arXiv: hep-ex/0607042
3 Chistov R et al (BELLE Collaboration). Phys. Rev. Lett., 2006, **97**: 162001
4 Aubert B et al (BABAR Collaboration). Phys. Rev. Lett., 2006, **97**: 232001
5 Aubert B et al (BABAR Collaboration). Phys. Rev. Lett., 2007, **98**: 012001
6 Mizuk R et al (BELLE Collaboration). Phys. Rev. Lett., 2007, **98**: 262001
7 CHEN C, CHEN X L, LIU X et al. Phys. Rev. D, 2007, **75**: 094017
8 Micu L. Nucl. Phys. B, 1969, **10**: 521
9 Le Yaouanc A, Oliver L, Pène O et al. Phys. Rev. D, 1973, **8**: 2223; D, 1974, **9**: 1415; D, 1975, **11**: 1272; Phys. Lett. B, 1977, **71**: 57; B, 1977, **71**: 397
10 Le Yaouanc A, Oliver L, Pène O et al. Phys. Lett. B, 1977, **72**: 57
11 Le Yaouanc A, Oliver L, Pène O et al. Hadron Transitions in the Quark Model. New York: Gordon and Breach Science Publishers, 1987
12 Blundell H G, Godfrey S. Phys. Rev. D, 1996, **53**: 3700
13 Page P R. Nucl. Phys. B, 1995, **446**: 189; Capstick S, Isgur N. Phys. Rev. D, 1986, **34**: 2809
14 Capstick S, Roberts W. Phys. Rev. D, 1994, **49**: 4570
15 Ackleh E S, Barnes T, Swanson E S. Phys. Rev. D, 1996, **54**: 6811
16 ZHOU H Q, PING R G, ZOU B S. Phys. Lett. B, 2005, **611**: 123
17 GUO X H, KE H W, LI X Q et al. Commun. Theor. Phys., 2007, **48**: 509—518
18 LU J, DENG W Z, CHEN X L et al. Phys. Rev. D, 2006, **73**: 054012; ZHANG B, LIU X, ZHU S L. Eur. Phys. J. C, 2007, **50**: 617
19 Capstick S, Roberts W. Phys. Rev. D, 1993, **47**: 1994
20 Blundell H G, Godfrey S. Phys. Rev. D, 1996, **53**: 3700
21 Close F E, Swanson E S. Phys. Rev. D, 2005, **72**: 094004
22 Capstick S, Isgur N. Phys. Rev. D, 1986, **34**: 2809