Masses of heavy-light mesons in Regge phenomenology *

QIN Zhen(秦臻)[1;1)] DONG Xin-Ping(董新平)[2;2)] WEI Ke-Wei(魏科伟)[3;3)]

[1] College of Mathematics and Information Science, North China University of Water Resources and Electric Power, Zhengzhou 450011, China
[2] College of Electric and Information Engineering, Xuchang University, Xuchang 461000, China
[3] College of Physics and Electrical Engineering, Anyang Normal University, Anyang 455002, China

Abstract: The masses of some orbitally and radially excited heavy-light mesons are calculated in Regge phenomenology. The results are in reasonable agreement with the experimental data and those given in many other theoretical approaches. Based on the calculation, we suggest that the recently observed D(2550), D(2600) and D(2760) can be assigned as the charmed members of the 2^1S_0, 2^3S_1 and 1^3D_1 multiplets, respectively. $\mathrm{D}^*_{\mathrm{s1}}(2700)^\pm$ may be assigned as the charm-strange member of the 2^3S_1 state. The results may be helpful in understanding the nature of current and future experimentally observed heavy-light mesons.

Key words: Regge phenomenology, heavy-light meson, mass spectrum

PACS: 11.55.Jy, 12.40.Nn, 14.40.-n **DOI:** 10.1088/1674-1137/37/5/053102

1 Introduction

Recently, some heavy-light mesons ($\mathrm{Q\bar{q}}$) with one heavy quark (Q=c, b) and one light quark (q=u, d, s) have been discovered. In the charmed meson sector, the discovery of new charmed mesons D(2550), D(2600), D(2610), D(2760) [1] and charmed-strange mesons $\mathrm{D_{s1}}(2700)$ [2, 3], $\mathrm{D^*_{sJ}}(2860)$ [2, 4], $\mathrm{D_s}(3040)$ [4] has aroused great interest. However, the assignments of quantum numbers for some of these resonances are still being disputed.

Although some B and $\mathrm{B_s}$ mesons have been observed by experiments [5–8], the detailed spectroscopy of the orbitally and radially excited states of B and $\mathrm{B_s}$ mesons has not been fully established experimentally. Heavy mesons with open and hidden heavy quarks are very important in understanding the quark model, the unperturbative properties of QCD and CP-violating phenomena. Therefore, the study of the spectrum of heavy mesons continues to be an active area in both theory and experiment.

To reproduce the available mass spectrum and predict the unobserved states of heavy-light mesons, a number of theoretical approaches have been proposed so far. These approaches include the Regge phenomenology [9–18], the lattice QCD [19, 20], the quark model [21–23], the potential model [24–30] and the relativistic quark potential model based on QCD [31–36].

The Regge theory is one of the most simple phenomenological models in studying the meson spectrum. By analyzing the slope ratios of Regge trajectories and the corresponding meson masses, the authors of Refs. [37, 38] proposed an approach to calculate the spectrum of mesons based on Regge theory. In this way, the authors of Refs. [38] have succeeded in predicting some $\mathrm{B_c}$ and hidden flavor heavy meson spectra.

Following the method demonstrated in Ref. [38], we will study the heavy-light meson spectrum in the present work. In order to study the $\mathrm{D_s}$ and $\mathrm{B_s}$ spectra, we will first calculate the masses of the $\mathrm{s\bar{s}}$ mesons of the $1S$, $1P$, $1D$, $2S$ and $2P$ multiplets using the slope ratios of the $\mathrm{n\bar{n}}$ and $\mathrm{s\bar{s}}$ states. Then the corresponding D, $\mathrm{D_s}$, B and $\mathrm{B_s}$ mass spectra will be extracted using the same model. We will compare the present results with those given in other approaches.

This paper is organized as follows. In Section 2 we briefly introduce the Regge trajectory model. In Section 3, using the available experimental data and some data from Ref. [34], we calculate the $1S$, $1P$, $1D$, $2S$ and $2P$ heavy-light meson spectra. Finally, we give a short discussion and summary in Section 4.

Received 26 June 2012, Revised 16 August 2012

∗ Supported by National Natural Science Foundation of China (10975018, 11147197, 11104072, U1204115) and Key Project of Scientific and Technological Research of Education Department of Henan Province (12B140001)

1) E-mail: qinzhenncwu@sohu.com
2) E-mail: dongxp@xcu.edu.cn
3) E-mail: weikw@hotmail.com

2 The Regge trajectory

In this section we will give a brief introduction to the Regge trajectory model.

Assuming the existence of the linear Regge trajectories for both light and heavy mesons, one can have

$$J=\alpha_{\mathrm{i\bar{j}}}(0)+\alpha'_{\mathrm{i\bar{j}}}M^2_{\mathrm{i\bar{j}}}, \tag{1}$$

where i and j denote the quark constituents, $\alpha_{\mathrm{i\bar{j}}}(0)$ and $\alpha'_{\mathrm{i\bar{j}}}$ are, respectively, the intercept and slope of the trajectory on which the $\mathrm{i\bar{j}}$ meson lies.

For a meson multiplet with spin-parity J^P, the parameters $\alpha_{\mathrm{i\bar{j}}}(0)$ and $\alpha'_{\mathrm{i\bar{j}}}$ with different quark constituents can be related by the following relations: the additivity of intercepts [10, 11]:

$$\alpha_{\mathrm{i\bar{i}}}(0)+\alpha_{\mathrm{j\bar{j}}}(0)=2\alpha_{\mathrm{i\bar{j}}}(0), \tag{2}$$

the additivity of inverse slopes [12]:

$$\frac{1}{\alpha'_{\mathrm{i\bar{i}}}}+\frac{1}{\alpha'_{\mathrm{j\bar{j}}}}=\frac{2}{\alpha'_{\mathrm{i\bar{j}}}}, \tag{3}$$

where i and j represent the quark flavors.

Using Eq. (1) and Eq. (2), one obtains

$$\alpha'_{\mathrm{i\bar{i}}}M^2_{\mathrm{i\bar{i}}}+\alpha'_{\mathrm{j\bar{j}}}M^2_{\mathrm{j\bar{j}}}=2\alpha'_{\mathrm{i\bar{j}}}M^2_{\mathrm{i\bar{j}}}, \tag{4}$$

where the meson states $\mathrm{i\bar{i}}$, $\mathrm{j\bar{j}}$ and $\mathrm{i\bar{j}}$ belong to the same $n^{2s+1}L_J$ multiplet.

When quark masses $m_{\mathrm{i}}<m_{\mathrm{j}}$, combining the relations (3) and (4), one can get the following relation between the slope ratio and meson masses:

$$\frac{\alpha'_{\mathrm{j\bar{j}}}}{\alpha'_{\mathrm{i\bar{i}}}}=\frac{(4M^2_{\mathrm{i\bar{j}}}-M^2_{\mathrm{i\bar{i}}}-M^2_{\mathrm{j\bar{j}}})+\sqrt{(4M^2_{\mathrm{i\bar{j}}}-M^2_{\mathrm{i\bar{i}}}-M^2_{\mathrm{j\bar{j}}})^2-4M^2_{\mathrm{i\bar{i}}}M^2_{\mathrm{j\bar{j}}}}}{2M^2_{\mathrm{j\bar{j}}}}. \tag{5}$$

Eq. (5) is a relation about three mesons involving two flavors in a spin-parity multiplet.

When i=n (n=u or d), j=s, one can have

$$\frac{\alpha'_{\mathrm{s\bar{s}}}}{\alpha'_{\mathrm{n\bar{n}}}}=\frac{(4M^2_{\mathrm{n\bar{s}}}-M^2_{\mathrm{n\bar{n}}}-M^2_{\mathrm{s\bar{s}}})+\sqrt{(4M^2_{\mathrm{n\bar{s}}}-M^2_{\mathrm{n\bar{n}}}-M^2_{\mathrm{s\bar{s}}})^2-4M^2_{\mathrm{n\bar{n}}}M^2_{\mathrm{s\bar{s}}}}}{2M^2_{\mathrm{s\bar{s}}}}. \tag{6}$$

When i=n, j=c, b, the slope ratios are, respectively,

$$\frac{\alpha'_{\mathrm{c\bar{c}}}}{\alpha'_{\mathrm{n\bar{n}}}}=\frac{(4M^2_{\mathrm{n\bar{c}}}-M^2_{\mathrm{n\bar{n}}}-M^2_{\mathrm{c\bar{c}}})+\sqrt{(4M^2_{\mathrm{n\bar{c}}}-M^2_{\mathrm{n\bar{n}}}-M^2_{\mathrm{c\bar{c}}})^2-4M^2_{\mathrm{n\bar{n}}}M^2_{\mathrm{c\bar{c}}}}}{2M^2_{\mathrm{c\bar{c}}}}. \tag{7}$$

$$\frac{\alpha'_{\mathrm{b\bar{b}}}}{\alpha'_{\mathrm{n\bar{n}}}}=\frac{(4M^2_{\mathrm{n\bar{b}}}-M^2_{\mathrm{n\bar{n}}}-M^2_{\mathrm{b\bar{b}}})+\sqrt{(4M^2_{\mathrm{n\bar{b}}}-M^2_{\mathrm{n\bar{n}}}-M^2_{\mathrm{b\bar{b}}})^2-4M^2_{\mathrm{n\bar{n}}}M^2_{\mathrm{b\bar{b}}}}}{2M^2_{\mathrm{b\bar{b}}}}. \tag{8}$$

When i=s, j=c, b, the slope ratios are, respectively,

$$\frac{\alpha'_{\mathrm{c\bar{c}}}}{\alpha'_{\mathrm{s\bar{s}}}}=\frac{(4M^2_{\mathrm{s\bar{c}}}-M^2_{\mathrm{s\bar{s}}}-M^2_{\mathrm{c\bar{c}}})+\sqrt{(4M^2_{\mathrm{s\bar{c}}}-M^2_{\mathrm{s\bar{s}}}-M^2_{\mathrm{c\bar{c}}})^2-4M^2_{\mathrm{s\bar{s}}}M^2_{\mathrm{c\bar{c}}}}}{2M^2_{\mathrm{c\bar{c}}}}. \tag{9}$$

$$\frac{\alpha'_{\mathrm{b\bar{b}}}}{\alpha'_{\mathrm{s\bar{s}}}}=\frac{(4M^2_{\mathrm{s\bar{b}}}-M^2_{\mathrm{s\bar{s}}}-M^2_{\mathrm{b\bar{b}}})+\sqrt{(4M^2_{\mathrm{s\bar{b}}}-M^2_{\mathrm{s\bar{s}}}-M^2_{\mathrm{b\bar{b}}})^2-4M^2_{\mathrm{s\bar{s}}}M^2_{\mathrm{b\bar{b}}}}}{2M^2_{\mathrm{b\bar{b}}}}. \tag{10}$$

Using the experimental data of the ground meson states, the slope ratios can then be obtained. By investigating the properties of the Regge slope, a number of important results are discovered. Regge slopes are independent of charge conjugation in accordance with the C-invariance of QCD [13]. The Regge slope of the radial excited state is the same as that of the corresponding ground state [14] and the slopes of the parity partners' trajectories coincide [15]. Therefore, the authors of Ref. [16] divided all the meson multiplets into the 1^1S_0-like multiplets and the 1^3S_1-like multiplets. The 1^1S_0-like and the 1^3S_1-like multiplets have unnatural parity $P=(-1)^{J-1}$ and natural parity $P=(-1)^J$, respectively. Mesons with the same flavors which belong to the 1^1S_0-like (1^3S_1-like) multiplets have the same slopes. Thus the slope ratio of the excited states is the same as that of the ground states. According to the relation mentioned above, the spectrum of excited states can be obtained using the slope ratios of ground states and the observed meson masses.

3 Numerical results

In order to invest the masses of the $\mathrm{c\bar{s}}$ and $\mathrm{b\bar{s}}$ states, we first need to get the $\mathrm{s\bar{s}}$ masses. Since we have obtained the masses of the ground $\mathrm{s\bar{s}}$ states based on the mass relation of mesons among six mesons in certain multiplets [39], we use Eq. (6) to calculate the excited $s\bar{s}$ masses.

To obtain the spectrum of excited heavy-light mesons based on Eqs. (6)–(10), we use the corresponding meson masses from PDG [40]. For the unobserved $c\bar{c}$ states of the 2^3P_0 and 2^3P_1 multiplets, we use the theoretical results from Ref. [38], which are also obtained based on the Regge phenomenology. For some unobserved states, we use the theoretical values in Ref. [34].

Using the masses of the corresponding states given by PDG and in the theoretical values [34], the slope ratios can be obtained from Eqs. (6)–(10). The slope ratios for the ground 1^1S_0 meson multiplets are $\alpha'_{s\bar{s}}/\alpha'_{n\bar{n}}|_{1^1S_0}=$ 0.9428, $\alpha'_{c\bar{c}}/\alpha'_{n\bar{n}}|_{1^1S_0}=$ 0.5641, $\alpha'_{b\bar{b}}/\alpha'_{n\bar{n}}|_{1^1S_0}=$ 0.2631, $\alpha'_{c\bar{c}}/\alpha'_{s\bar{s}}=|_{1^1S_0}0.5990$, $\alpha'_{b\bar{b}}/\alpha'_{s\bar{s}}=|_{1^1S_0}0.2811$. The slope ratios for the ground 1^3S_1 meson multiplets are $\alpha'_{s\bar{s}}/\alpha'_{n\bar{n}}|_{1^3S_1}$=0.8670, $\alpha'_{c\bar{c}}/\alpha'_{n\bar{n}}|_{1^3S_1}$=0.4927, $\alpha'_{b\bar{b}}/\alpha'_{n\bar{n}}|_{1^3S_1}=$ 0.2628, $\alpha'_{c\bar{c}}/\alpha'_{s\bar{s}}|_{1^3S_1}=$ 0.5682, $\alpha'_{b\bar{b}}/\alpha'_{s\bar{s}}|_{1^3S_1}=$ 0.2548, respectively.

The numerical results of the excited heavy-light meson spectrum can then be calculated using the slope ratios and Eqs. (6)–(10). The comparison of the masses of the excited states obtained in the present work and those given by experiments and in other works is shown

Table 1. The masses of the $s\bar{s}$ mesons (in MeV).

state	1^1S_0	1^3S_1	1^1P_1	1^3P_0	1^3P_1	1^3P_2	1^3D_1	2^1S_0	2^3S_1	2^3P_0	2^3P_1	2^3P_2
$s\bar{s}$	697	1009	1445	1543	1445	1540	1841	1611	1861	1903	2039	2060

Table 2. The masses of the $c\bar{n}$(n=u,d) mesons (in MeV).

$n^{2S+1}l_J$	Theo.	Ref. [22]	Ref. [30]	Ref. [31]	Ref. [32]	Ref. [35]	Ref. [36]	PDG [40]
1^1P_1	2431	2417	2421	2425	2501	2469	2490	2423
1^3P_0	2449	2252	2279	2283	2438	2406	2403	
1^3P_1	2422	2402	2407	2421	2414	2426	2417	2427
1^3P_2	2457	2466	2465	2468	2459	2460	2460	2460
1^3D_1	2749	2740	2762	2788	2795			
2^1S_0	2519	2555	2548	2579	2581	2589		
2^3S_1	2588	2636	2647	2629	2632			
2^3P_0	2780	2752	2919					
2^3P_1	2782	2886	2932	2995				
2^3P_2	2823	2971	3012	3035				

Table 3. The masses of the $c\bar{s}$ mesons (in MeV).

$n^{2S+1}l_J$	Theo.	Ref. [22]	Ref. [30]	Ref. [31]	Ref. [32]	Ref. [35]	Ref. [36]	PDG [40]
1^1P_1	2522	2510	2537	2525	2569	2574	2605	2535
1^3P_0	2493	2344	2388	2325	2508	2509		2318
1^3P_1	2514	2488	2521	2467	2515	2536	2535	2460
1^3P_2	2570	2559	2573	2568	2560	2571	2581	2573
1^3D_1	2814	2804		2817		2913	2913	2709
2^1S_0	2650	2640	2657		2670	2688	2700	
2^3S_1	2697	2714	2758		2716	2731		
2^3P_0	2853	2830				3054		
2^3P_1	2961	2958				3067	3114	
2^3P_2	2985	3040				3142	3157	

Table 4. The masses of the $b\bar{n}$(n=u,d) mesons (in MeV).

$n^{2S+1}l_J$	Theo.	Ref. [30]	Ref. [31]	Ref. [32]	Ref. [35]	Ref. [36]	PDG [40]
1^1P_1	5724	5744	5720	5757	5774	5742	5721
1^3P_0	5729	5690	5592	5738	5749		
1^3P_1	5720	5731	5649	5719	5723	5700	
1^3P_2	5706	5759	5737	5733	5741	5714	5743
1^3D_1	5914		6999		6119	6025	
2^1S_0	5800	5892		5883	5890	5886	
2^3S_1	5820	5924		5898	5906		
2^3P_0	5999				6221		
2^3P_1	6071				6209	6175	
2^3P_2	6038				6260	6188	

Table 5. The masses of the b$\bar{s}$ mesons (in MeV).

$n^{2S+1}l_J$	Theo.	Ref. [30]	Ref. [31]	Ref. [32]	Ref. [35]	Ref. [36]	PDG [40]
1^1P_1	5811	5860	5831	5859	5831	5842	5829
1^3P_0	5775	5810	5617		5833		
1^3P_1	5807	5855	5682	5831	5865	5805	
1^3P_2	5809	5875	5847	5844	5842	5820	5840
1^3D_1	5983		6048		6209	6127	
2^1S_0	5917	6001		5971	5976	5985	
2^3S_1	5982	6036		5984	5992		
2^3P_0	6108				6318	6019	
2^3P_1	6199				6281	6278	
2^3P_2	6189				6359	6292	

in Table 1 to Table 5. From Tables 2–5, one can see that the masses of the heavy-light mesons given in the present work are very close to the experimental data. The masses of the mesons given in the present work are in reasonable agreement with those given in many other approaches. A detailed discussion will be given in Section 4.

4 Discussion and summary

In the Regge phenomenology, the slope ratios of the 1^1S_0 and 1^3S_1 multiplets are obtained by using the experimental values of the corresponding meson masses. Then, the masses of the excited states are calculated based on the relation between the meson masses and the related slope ratios.

As shown in Table 2, the predicted mass of the 2^1S_0 c$\bar{n}$ state (2519 MeV) agrees with the newly discovered D(2550) resonance by BaBar [1] (2539 MeV), which also agrees with the results given in the theoretical approaches [41–43].

The calculated mass of the 2^3S_1 c$\bar{n}$ state (2588 MeV) is very close to the newly discovered D(2600) resonance by BaBar [1] (2609 MeV).

The masses of D(2760) given by BaBar [1] and Ref. [35] are 2763 MeV and 2788 MeV, respectively. The mass of the $1^3D_1(1^-)$ state predicted in the present work is 2749 MeV, which is in agreement with the result of Ref. [35]. So we suggest that D(2760) may be a $1^3D_1(1^-)$ state.

From Table 3, the predicted c$\bar{s}$ masses are in good agreement with the experimental data and other theoretical approaches. $D^*_{s1}(2700)^\pm$ is assigned as a $1^3D_1(1^-)$ state in PDG. However, our predicted mass of $1^3D_1(1^-)$ is 2814 MeV. The theoretical mass of Ref. [35] for the $1^3D_1(1^-)$ state is 2913 MeV. So, $D^*_{s1}(2700)^\pm$ may not be a $1^3D_1(1^-)$ state based on the mass spectrum. The calculated mass of the 2^3S_1 state from Table 2 is 2697 MeV, which agrees with $D^*_{s1}(2700)^\pm$. Therefore, we suggest $D^*_{s1}(2700)^\pm$ is more like a candidate of a 2^3S_1 state, which agrees with the results given in other approaches [35, 44–46]. The recent investigation of the decay properties supports this assignment too. Using an effective Lagrangian approach, the authors of Ref. [47] calculated the ratio of $\Gamma(D_{s1}(2700)\rightarrow \mathrm{D^*K})/\Gamma(\mathrm{D_{s1}}(2700)\rightarrow \mathrm{DK})$, which is very close to the experimental value [4]. Such an analysis indicates that it is reasonable for $D_{s1}(2700)$ to be assigned as a $2^3S_1(1^-)$ c$\bar{s}$ state. The assignment is also supported by the calculation based on the Bethe-Salpeter method [48] and the semiclassical flux tube mode [49].

From Table 4 and Table 5, our predicted masses of 1^1P_1, 1^3P_2 B and $\mathrm{B_s}$ mesons agree well with the experimental results. The predictions of those unobserved B and Bs states are in agreement with other theoretical approaches. Such predictions are important for the future study of unobserved heavy-light mesons.

In summary, we succeed in reproducing the observed light-heavy meson spectrum by using the Regge trajectory model. The predicted masses of some unobserved higher excited states are in good agreement with those given in other theoretical approaches.

Based on the results, we suggest that D(2550), D(2600) and D(2760) are candidates for the charmed members of the excited 2^1S_0, 2^3S_1 and 1^3D_1 states, respectively. We support $D^*_{s1}(2700)^\pm$ being assigned as the charm-strange member of the 2^3S_1 state. The predictions will be helpful for understanding the nature of current and future experimentally observed heavy-light mesons.

References

1 Sanchez P et al. (BABAR collaboration). Phys. Rev. D, 2010, **82**: 111101
2 Aubert B et al. (BABAR collaboration). Phys. Rev. Lett., 2006, **97**: 222001
3 Brodzicka J et al. (Belle collaboration). Phys. Rev. Lett., 2008, **100**: 092001
4 Aubert B et al. (BABAR collaboration). Phys. Rev. D, 2009, **80**: 092003
5 Akers R et al. (OPAL collaboration). Z. Phys. C, 1995, **66**: 19
6 Aaltonen T et al. (CDF collaboration). Phys. Rev. Lett., 2007, **99**: 172001
7 Aaltonen T et al. (CDF collaboration). Phys. Rev. Lett., 2008, **100**: 082001
8 Aaltonen T et al. (CDF collaboration). Phys. Rev. Lett., 2009, **102**: 102003
9 Regge T. Nuovo Cim., 1959, **14**: 951
10 Regge T. Nuovo Cim., 1960, **18**: 947
11 Kawarabayashi K, Kitakado S, Yabuki H. Phys. Lett. B, 1969, **28**: 432
12 Kaidalov A B. Z. Phys. C, 1982, **12**: 63
13 Brisudova M M, Burakovsky L, Goldman T. Phys. Rev. D, 2000, **61**: 054013
14 Anisovich A V, Anisovich V V, Sarantsev A V. Phys. Rev. D, 2000, **62**: 051502(R)
15 Chan H M, Hsue C S, Quigg C et al. Phys. Rev. Lett., 1971, **26**: 672
16 LI De-Min, MA Bing, LI Yu-Xiao et al. Eur. Phys. J. C, 2004, **37**: 323
17 ZHANG Ai-Lin. Phys. Rev. D, 2005, **72**: 017902
18 Afonin S S, Int. J. Mod. Phys. A, 2005, **22**: 4537
19 CHIU Ting-Wai, HSIEH Tung-Han, HUANG Chao-Hsi et al. Phys. Lett. B, 2007, **651**: 171
20 Davies C T H, Hornbostel K, Lepage G P et al. Phys. Lett. B, 1996, **382**: 131
21 Ebert D, Faustov R N, Galkin V O. Phys. Rev. D, 2003, **67**: 014027
22 LI De-Min, JI Peng-Fei, MA Bing. Eur. Phys. J. C, 2011, **71**: 1582
23 Godfrey S. Phys. Rev. D, 2004, **70**: 054017
24 Eichten E J, Quigg C. Phys. Rev. D, 1994, **49**: 5845
25 Gershtein S S, Kiselev V V, Likhoded A K et al. Phys. Rev. D, 1995, **51**: 3613
26 CHEN Yu-Qi, KUANG Yu-Ping. Phys. Rev. D, 1992, **46**: 1165
27 Fulcher L P. Phys. Rev. D, 1999, **60**: 074006
28 Patel B, Vinodkumar P C. J. Phys. G, 2009, **36**: 035003
29 Gupta S N, Johnson J M. Phys. Rev. D, 1996, **53**: 312
30 Gupta S N, Johnson J M. Phys. Rev. D, 1995, **51**: 168
31 Matsuki T, Morii T, Sudoh K. Prog. Theor. Phys., 2007, **117**:1077
32 Ebert D, Faustov R N, Galkin V O. Phys. Rev. D, 1998, **57**: 5663
33 Ebert D, Faustov R N, Galkin V O. Mod. Phys. Lett. A, 2005, **20**: 1887
34 Ebert D, Faustov R N, Galkin V O. Phys. Rev. D, 2009, **79**: 114029
35 Ebert D, Faustov R N, Galkin V O. Eur. Phys. J. C, 2010, **66**: 197
36 Di Pierro M, Eichten E. Phys. Rev. D, 2001, **64**: 114004
37 GUO Xin-Heng, WEI Ke-Wei, WU Xing-Hua. Phys. Rev. D, 2008, **78**: 056005
38 WEI Ke-Wei, GUO Xin-Heng. Phys. Rev. D, 2010, **81**: 076005
39 WEI Ke-Wei, DONG Xin-Ping, LÜ Gang. Int. J. Mod. Phys. A, 2011, **26**: 2065
40 Nakamura K et al. (Particle Data Group). J. Phys. G, 2010, **37**: 075021
41 GUO Feng-Kun, Meissner U G. Phys. Rev. D, 2011, **84**: 014013
42 ZHONG Xian-Hui. Phys. Rev. D, 2010, **82**: 114014
43 CHEN Bing, YUAN Ling, ZHANG Ai-Lin. Phys. Rev. D, 2011, **83**: 114025
44 Godfrey S, Isgur N. Phys. Rev. D, 1985, **32**: 189
45 Matsuki T, Morii T, Sudoh K. Eur. Phys. J. A, 2007, **31**: 701
46 Badalian A M, Bakker B L G. Phys. Rev. D, 2011, **84**: 034006
47 Colangelo P, De Fazio F, Nicotri S. Phys. Rev. D, 2008, **77**: 014012
48 WANG Guo-Li, ZHANG Jin-Mei, WANG Zhi-Hui. Phys. Lett. B, 2009, **681**: 326
49 CHEN Bing, WANG Deng-Xia, ZHANG Ai-Lin. Phys. Rev. D, 2009, **80**: 071502