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Unquenched Vector Mesons with Open-Beauty

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I. Introduction

Mesons with Open-Beauty: Experimental Status

bn	Decays	J^P	bs	Decays	J^P	bc	Decays	J^P
$B[5279]$	weak	0^-	$B_s[5367]$	weak	0^-	$B_c[6277]$	weak	0^-
$B^*[5325]$	$B\gamma$	1^-	$B^*[5415]$	$B_s\gamma$	1^-			
$B_1(5721)^0$	$B^*\pi$	1^+ ?	$B_{s1}(5830)^0$	B^*K	1^- ?			
$B_J^*(5732)$	$B^*\pi,\ B\pi$	?						
$B_2(5747)$	$B\pi,\ B^*\pi$	2^+ ?	$B_2^*(5840)$	$BK,\ B^*K$	2^+ ?			
$B(5970)$	$B\pi$	?	$B_{sJ}^*(5850)$	?	?			

Vectors (most recent observations):

B^*: PRL 110, 151803 (2013) [LHCb]

B_s^*: PRL 102, 021801 (2009) [Belle]

Recent observation: $B(5970)$ PRD 90, 012013 (2014) [CDF] - is it a vector?

Puzzles within the Vectors

	B^*	B_s^*	D^*	D_s^* ?	K^*
exp data	5325	5415	2009	2112	892
first th (OZI)	$B\pi$ 5417	BK 5775	$D\pi$ 2005	DK 2363	$K\pi$ 634
BE	-92	-360	+4	-251	+258

	ρ, ω	ϕ	J/ψ	Υ
exp data	775/783	1020	3097	9460
first th (OZI)	$\pi\pi$ 275	KK 991	DD 3734	BB 10559
BE	+501/+508	+28	-638	-1099

Some lattice results concerning the B mesons:

PRD 62, 114507 (2000); PRD 69, 094505 (2004)
arXiv: 1501.01646 [hep-lat]

and Phenomenological Models:

PRD 89, 074042 (2014) unitarized approach
PRD 85, 094008 (2012) one-boson-exchange.

Unquenching in the models

QED - good knowledge of energy levels in H atom. well defined potential, well known spin-orbit corrections.

QCD - wished the energy levels of hadrons would be quenched and perturbative. In this case a confining potential would be clearly defined!

Some quenched models, e.g., Godfrey-Isgur model, assume meson spectrum as a bare spectrum of the underlying "funnel" (i.e. Coulomb + linear term) potential, with spin-orbit corrections, without considering any other relevant hadronic degrees of freedom. All states that do not fit in this spectrum must be considered 'exotic'.

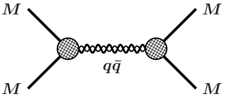
However this approaches fail to reproduce data, which reveals many nonperturbative effects that cannot be justified by spin-orbit corrections, namely deformation of Breit-Wigner line shapes and mass energies very different from the underlying spectrum.

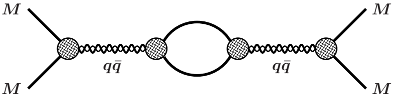
Unquenched approaches consider that resonances are not pure states, instead they are strongly coupled to other important components of the hadronic *sea* and to the nearby decay channels.

II. The Resonance Spectrum Expansion (RSE) Model

Elastic-Scattering: $AB \to CD$, A, B, C, D are strongly interacting states.

Here, they are non-exotic mesons M. Born expansion:

$V =$ 

$V\Omega V =$ 

– free meson-meson MM

– confined $q\bar{q}$ which includes a whole radial spectrum.

Transition mechanism: $q\bar{q}$ annihilation/creation at the vertices, $^3P_0$ model.

Decays according to the Okubo-Zweig-Iizuka OZI rule.

Effective potential, in momentum space:

$$V_{ij}(p_i, p_j'; E) = \lambda^2 j^i_{L_i}(p_i a) R_{ij}(E) j^j_{L_j}(p_j' a)$$

String breaking - Spherical Bessel function $\Leftrightarrow$ spherical delta function

Free parameters:

a - "string-breaking" distance

λ - global coupling

RSE formula:

$$\mathcal{R}_{ij} = \sum_{l_c, S} \sum_{n=0}^{\infty} \frac{g^i_{nl_cS}\ g^j_{nl_cS}}{E - E_n^{(l_c)}}$$

Coupling constants $g^i_{nl_cS}$, i, j - decay channels

the g's are computed within the $^3P_0$ model using expansions on a harmonic-oscillator basis

$g_n = r_n/4^n$, where r_n is a polynomial - rapid convergence of the series

Separable potential, Lippmann-Schwinger is evaluated in closed form.

Transition matrix:

$$T_{ij}^{L_i,L_j}(p_i,p_j';E) = -2a\lambda^2\sqrt{\mu_i p_i}j_{L_i}^i(p_i a)\sum_{m=1}^{N}\mathcal{R}_{im}\{[\mathbb{1}-\Omega\mathcal{R}]^{-1}\}_{mj}j_{L_j}^j(p_j' a)\sqrt{\mu_j p_j'},$$

$$\Omega_{ij}(k_j) = -2ia\lambda^2\mu_j k_j\, j_{L_j}^j(k_j a)\, h_{L_j}^{(1)j}(k_j a)\,\delta_{ij}\ .$$

Harmonic-oscillator confining potential:

known solutions, good results in phenomenological applications

$$E_n = m_q + m_{\bar{q}} + \omega(2n + l_c + 3/2)$$

Manifest unitarity of the scattering matrix - results are unquenched.

$$S = 1 + 2iT$$

Resonances and bound states are poles of the scattering matrix

(found in the 2nd Riemann Sheet in relation to the nearest threshold)

III. Vector Mesons with Open Beauty

The B^* spectrum within the RSE:

B^{*0}, $B^{*\pm}$	Channel	Th (GeV)	$g^2_{n=0,l=0}$	$g^2_{n=0,l=2}$
(bn+nn) PP	$B\pi$	5.417	0.02083	0.00694
	$B\eta$	5.827	0.00439	0.00146
	$B\eta'$	6.237	0.00255	0.00085
PV	$B\rho$	6.055	0.08333	0.00694
	$B\omega$	6.062	0.02778	0.00231
	$B^*\pi$	5.463	0.08333	0.00694
	$B^*\eta$	5.873	0.01758	0.00146
	$B^*\eta'$	6.283	0.00255	0.00085
VV	$B^*\rho$	6.101	0.00694	0.00231
	$B^*\rho$	6.101	0.13889	0.00046
	$B^*\omega$	6.108	0.00231	0.00077
	$B^*\omega$	6.108	0.04630	0.00015
(bs+sn) PP	B_sK	5.862	0.01389	0.00463
PV	B_sK^*	6.261	0.05556	0.00463
	B_s^*K	5.911	0.05556	0.00463
VV	$B_s^*K^*$	6.309	0.00463	0.00154
	$B_s^*K^*$	6.309	0.09259	0.00031

The B_s^* spectrum within the RSE:

B_s^{*0}	Channel	Th (GeV)	$g^2_{n=0,l=0}$	$g^2_{n=0,l=2}$
(bn+ns) PP	BK	5.775	0.02778	0.00926
PV	B^*K	5.821	0.11111	0.00926
	BK^*	6.173	0.11111	0.00926
VV	B^*K^*	6.219	0.00926	0.00309
VV	B^*K^*	6.219	0.18519	0.00062
(bs+ss) PP	$B_s\eta$	5.915	0.00510	0.00170
	$B_s\eta'$	6.324	0.00879	0.00293
	$B_s\phi$	6.386	0.05556	0.00463
PV	$B_s^*\eta$	5.963	0.02040	0.00170
	$B_s^*\eta'$	6.373	0.03515	0.00293
VV	$B_s^*\phi$	6.435	0.00463	0.00154
	$B_s^*\phi$	6.435	0.09259	0.00031

$$g_{n,l=0} = (2n/3+1)/4^n, \quad g_{n,l=2} = (n+1)/4^n$$

Fixed parameters (MeV),cf. PRD 27, 1527 (1983), and for m_b EPJ 32, 493 (2004):

$$\omega = 190, \quad m_n = 406, \quad m_s = 508, \quad m_c = 1562, \quad m_b = 4877$$

$$E_{n=0,1,2}\ (MeV): \quad (bn)\ \ 5568 \quad 5948 \quad 6328 \qquad (bs)\ \ 5670 \quad 6050 \quad 6430$$

		RSE (HO)	Experimental Data	Quenched Models †
bn	1S	5327	B^*, 5325	(1S) 5.32-5.37
r_0=2 GeV^{-1}	2S,1D	$5748 - i5$	B_J^*, $5698 - i64$?	(2S) 5.90-5.94
λ=10	2S,1D	$5845 - i1$	B_2, $5743 - i11$?	(1D) 6.02-6.12
	3S,2D	$6214 - i5$	$B(5970)$?	(3S) 6.34-6.39
	3S,2D	$6273 - i0$	[$5970 - i35$]	(2D) 6.47-6.54
bs	1S	5417	B_s^*, 5415	(1S) 5.41-5.45
r_0=2 GeV^{-1}	2S,1D	$5899 - i2$		(2S) 5.99-6.02
λ=6.3	2S,1D	$5980 - i4$	B_{sJ}^*, $5853 - i23$?	(1D) 6.12-6.21
	3S,2D	$6336 - i9$		(3S) 6.43-6.48
	3S,2D	$6378 - i1$		(2D) 6.54-6.63

† cf. PRD 89, 054026 (2014)

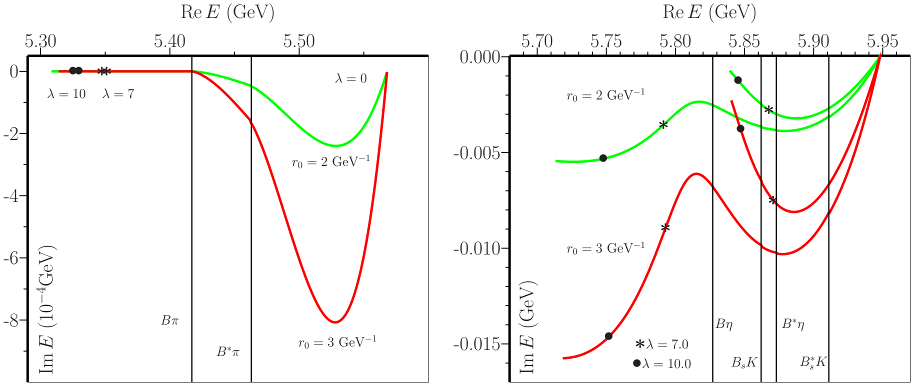
bn		RSE (HO)	Exp Data	Quenched Models †
	1S	5327	B^*, 5325	(1S) 5.32-5.37
r_0=2 GeV^{-1}	2S,1D	$5748 - i5$	$B(5970)$?	(2S) 5.90-5.94
λ=10	2S,1D	$5845 - i1$		(1D) 6.02-6.12
	3S,2D	$6214 - i5$		(3S) 6.34-6.39
	3S,2D	$6273 - i0$		(2D) 6.47-6.54
	1S	5347		
r_0=2 GeV^{-1}	2S,1D	$5791 - i4$		
λ=7	2S,1D	$5868 - i3$		
	1S	5351		
r_0=3 GeV^{-1}	2S,1D	$5793 - i9$		
λ=7	2S,1D	$5871 - i3$		

† cf. PRD 89, 054026 (2014).

Without increasing the constituent mass $m_b = 4.877$ GeV to around 5 GeV we do not find any pole around 5.97 GeV.

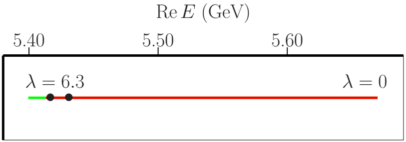
A proper adjustment of m_b should be done comparing the results of the RSE model to other quantum numbers.

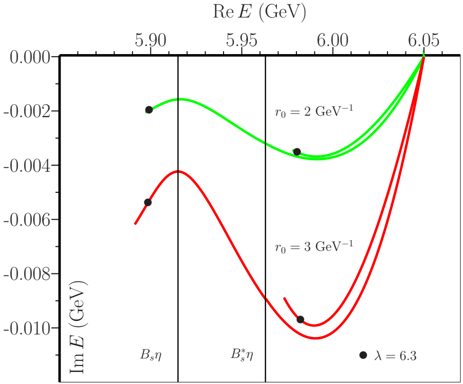
B^*, n=0 and n=0,1

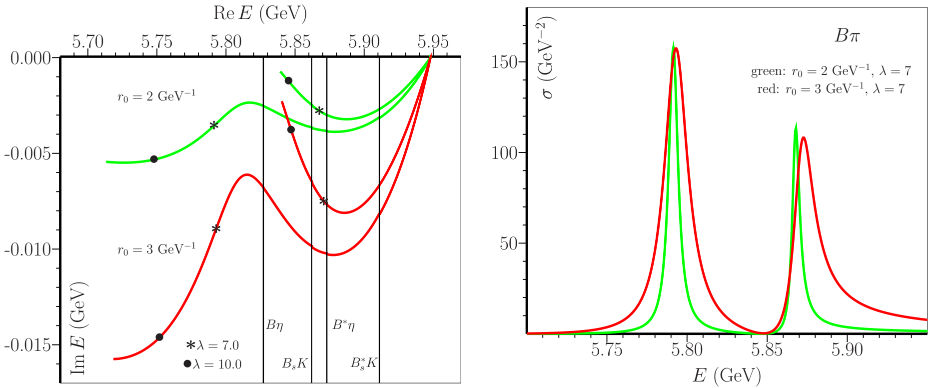


Re E (GeV)
5.30
5.40
5.50
0
-2
-4
-6
-8
λ = 10
λ = 7
λ = 0
r0 = 2 GeV−1
r0 = 3 GeV−1
Bπ
B*π
Im E (10−4GeV)
Re E (GeV)
5.70
5.75
5.80
5.85
5.90
5.95
0.000
-0.005
-0.010
-0.015
r0 = 2 GeV−1
r0 = 3 GeV−1
*λ = 7.0
●λ = 10.0
Bη
BsK
B*η
B*sK
Im E (GeV)

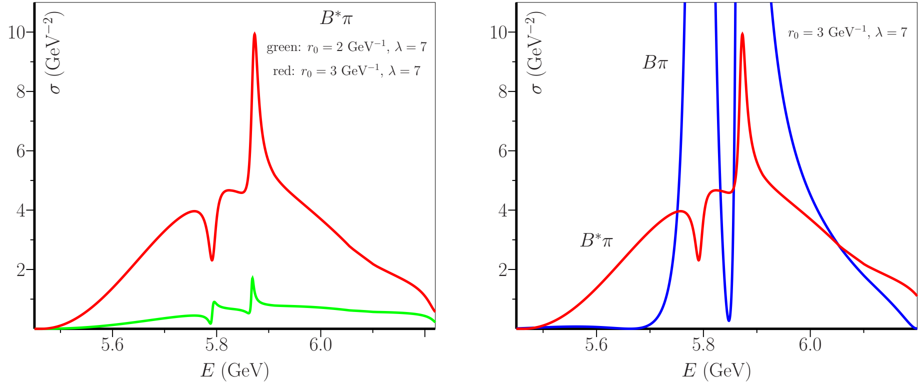
B_s^*, n=0 and n=0,1


Re E (GeV)
5.40
5.50
5.60
$\lambda = 6.3$
$\lambda = 0$


Re E (GeV)
5.90
5.95
6.00
6.05
0.000
-0.002
-0.004
-0.006
-0.008
-0.010
Im E (GeV)
$r_0 = 2$ GeV^{-1}
$r_0 = 3$ GeV^{-1}
$B_s\eta$
$B_s^*\eta$
$\lambda = 6.3$



Re E (GeV)
5.70
5.75
5.80
5.85
5.90
5.95
0.000
-0.005
-0.010
-0.015
Im E (GeV)
$r_0 = 2$ GeV^{-1}
$r_0 = 3$ GeV^{-1}
$B\eta$
$B^*\eta$
B_sK
B_s^*K
$*\lambda = 7.0$
$\bullet\lambda = 10.0$
σ (GeV^{-2})
150
100
50
$B\pi$
green: $r_0 = 2$ GeV^{-1}, $\lambda = 7$
red: $r_0 = 3$ GeV^{-1}, $\lambda = 7$
5.75
5.80
5.85
5.90
E (GeV)



$B^*\pi$
green: $r_0 = 2$ GeV^{-1}, $\lambda = 7$
red: $r_0 = 3$ GeV^{-1}, $\lambda = 7$
σ (GeV^{-2})
E (GeV)
5.6
5.8
6.0
2
4
6
8
10
$r_0 = 3$ GeV^{-1}, $\lambda = 7$
$B\pi$
$B^*\pi$
σ (GeV^{-2})
E (GeV)

Vector Mesons with Open Charm

		RSE (HO)	Experimental Data
cn	1S	2010	$D^*(2007)^0$, $2007 - i < 1.1$
r_0=2 GeV^{-1}			$D^*(2010)^{\pm}$, $2010 - i0.48$
λ=5.6	2S,1D	$2488 - i3$	$D(2460)$, $2461 - i25$?
	2S,1D	$2570 - i4$	$D(2600)$, $2609 - i45$?
cs	1S	2113	D_s^*, $2112 - i < 1$
r_0=2 GeV^{-1}	2S,1D	$2601 - i2$	
λ=4.5	2S,1D	$2691 - i4$	

VI. Summary and Conclusions

- The resonances with open bottom are still very poorly known from the experimental, and from the theoretical point of view.

- The unquenched and unitarized Resonance-Spectrum-Expansion model gives different predictions than the quenched models.

- The newly observed B(5970) is unlikely to be a vector within the RSE.

- More data is needed in the energy region between 4 and 10 GeV.

$\therefore$

Domo arigato gozaimashita!