Isospin violating decays of positive parity D_s and B_s mesons

Anita Prapotnik Brdnik

October 20, 2016

Faculty of civil engineering, transportation engineering and architecture // Belica 2016

Overview

1. **Introduction**
2. **The $D_{s0}^{*+}(2137)$ and $D_{s1}^{+}(2460)$ puzzle**
3. **Decays of positive parity D_s and B_s mesons**
4. **Heavy meson chiral perturbation theory**
5. $1^+ \to 0^- \pi\pi$ **decay modes**
6. $1^+ \to 1^- \pi$ **and** $0^+ \to 0^- \pi$ **decays**
7. **Overview**
8. **Conclusions**

Mesons

- u or d quark π
- s and u or d: K
- c and u or d: D
- c and s: D_s
- b and u or d: B
- b and s: B_s

Meson angular momentum quantum numbers for *L* = 0, 1, 2, 3

S	*L*	*J*	*P* (See below)	J^P
0	0	0	−	0^-
	1	1	+	1^+
	2	2	−	2^-
	3	3	+	3^+
1	0	1	−	1^-
	1	2, 1, 0	+	$2^+, 1^+, 0^+$
	2	3, 2, 1	−	$3^-, 2^-, 1^-$
	3	4, 3, 2	+	$4^+, 3^+, 2^+$

Types of mesons[19]

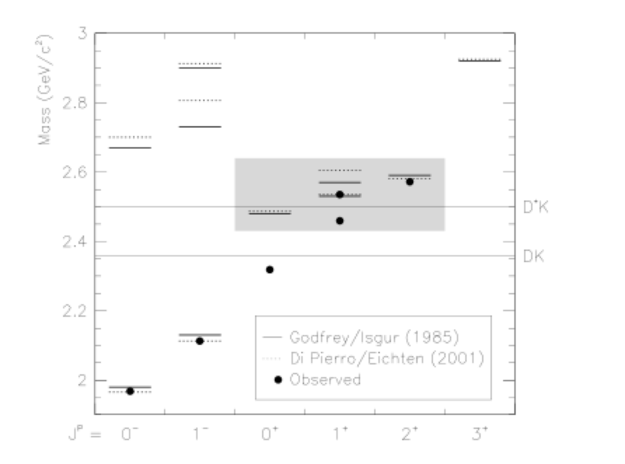
Type	*S*	*L*	*P*	*J*	J^P
Pseudoscalar meson	0	0	−	0	0^-
Pseudovector meson	1	1	+	1	1^+
Vector meson	1	0	−	1	1^-
Scalar meson	1	1	+	0	0^+
Tensor meson	1	1	+	2	2^+

$$D_{s0}(2317)^{*\pm}$$

The D_s meson spectrum

Particle	L	S	J^P	mass [MeV]	decay width
$D_s^{\pm}$	0	0	0^-	1968	$\tau = 500 \times 10^{-15}$ s
$D_s^{*\pm}$	0	1	$1^-?$	2112	< 1.9 MeV
$D_{s0}(2317)^{*\pm}$	1	1	0^+	2317	< 3.8 MeV
$D_{s1}(2460)^{\pm}$	1	0	1^+	2460	< 3.5 MeV
$D_{s1}(2536)^{\pm}$	1	1	1^+	2535	0.92 MeV
$D_{s2}^{*}(2573)^{\pm}$	1	1	$2^+?$	2572	17 MeV
$D_{s1}^{*}(2700)^{\pm}$	2	1	1^-	2709	117 MeV

The D_s meson spectrum



BABAR Phys. Rev. D 74, 031103 (2006); hep-ex/0604030

The $D_{s0}^{*+}(2137)$ and $D_{s1}^{+}(2460)$ puzzle

- $D_{s0}^{*+}(2137)$ and $D_{s1}^{+}(2460)$ are exotic states (tetraquark, DK molecule).
  K. Terasaki, Phys. Rev. D68; T. Barnes, F. E. Close and H. J. Lipkin, Phys. Rev. D68; A. P. Szczepaniak, Phys. Lett. B567; T. E. Browder, S. Pakvasa and A. A. Petrov, Phys. Lett. B578
- Masses can be understood when we take into account $1/m_c$ corrections.
  Fayyazuddin and Riazuddin, Phys. Rev. D69; R. N. Cahn and J. D. Jackson, Phys. Rev. D68; A. Deandrea, G. Nardulli and A. D. Polosa, Phys. Rev. D68; M. Sadzikowski, Phys. Lett. B579; W. Lucha and F. F. Schoberl, Mod. Phys. Lett. A18.
- DK threshold may play an important role in explaining $D_{s0}^{*+}(2137)$ and $D_{s1}^{+}(2460)$ mass. *Luka Leskovec, C.B. Lang, Daniel Mohler, Sasa Prelovsek, R.M. Woloshyn.*
- It is important to look at $D_{s0}^{*+}(2137)$ and $D_{s1}^{+}(2460)$ decay modes, especially radiative decay modes *$D_{s0}^{*+}(2137)$ and $D_{s1}^{+}(2460)$; S. Godfrey and R. Kokoski, Phys. Rev. D43.*

Colangelo et al, Mod. Phys. Lett. A19, 2083 (2004); hep-ph/0407137

The B_s masses [MeV]

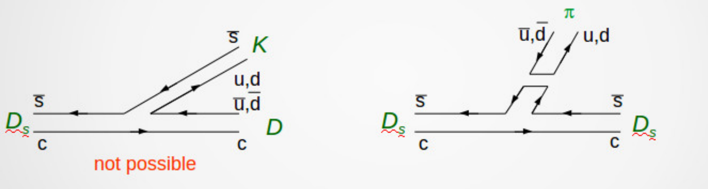
Particle	L	S	J^P	PDG	lattice [1]
B_s^0	0	0	0^-	5367	
B_s^{*0}	0	1	1^+	5415	
	1	1	0^+		5711
	1	0	1^+		5750
$B_{s1}(5830)^0$	1	1	1^+	5829	5831
$B_{s2}^*(5840)^0$	1	1	2^+	5840	5853

[1] C.B. Lang, D. Mohler, S. Prelovsek, R.M. Woloshyn, Phys. Lett. B 750 (2015)

relativistic quark models: D. Erbert et. al. (EPJ C 66 - 2010); M. Di Pierro et. al. (PRD 64 -2001), Y. Sun et. al. PRD 895 (2014)

The $D_{s0}^{*+}(2137)$ and $D_{s1}^{+}(2460)$ decay modes

- isospin violating strong decay modes
- radiative decay modes



The D_s meson spectrum

Decay Channel	$D^*_{sJ}(2317)^+$	$D_{sJ}(2460)^+$
$D_s^+\pi^0$	Seen	Forbidden
$D_s^+\gamma$	Forbidden	Seen
$D_s^+\pi^0\gamma$ (a)	Allowed	Allowed
$\quad D_s^*(2112)^+\pi^0$	Forbidden	Seen
$\quad D^*_{sJ}(2317)^+\gamma$	—	Allowed
$D_s^+\pi^0\pi^0$	Forbidden	Allowed
$D_s^+\gamma\gamma$ (a)	Allowed	Allowed
$\quad D_s^*(2112)^+\gamma$	Allowed	Allowed
$D_s^+\pi^+\pi^-$	Forbidden	Seen

(a) Non-resonant only

BABAR Phys. Rev. D 74, 031103 (2006); hep-ex/0604030

Isospin violating decay modes

$D_{s0}(2317)^{*\pm}$ decays	BR
$D_s^+\pi^0$	seen
$D_s^+\pi^0\pi^0$	not seen
$D_{s1}(2460)^{\pm}$ decays	BR
$D_s^{*+}\pi^0$	$(48 \pm 11)\%$
$D_s^+\gamma$	$(18 \pm 4)\%$
$D_s^+\pi^+\pi^-$	$(4.3 \pm 1.3)\%$
$D_s^{*+}\gamma$	$< 8\%$
$D_{s0}^*(2317)^+\gamma$	$(3.7^{+5.0}_{-2.4})\%$

Heavy meson chiral perturbation theory

- We cannot use QCD Lagrangian perturbation as strong coupling constant is too large in this energy region.
- Effective theory: we look at the additional symmetries that are specific to the decay process and use it to find an effective Lagrangian that can be solved by perturbation. Instead of quarks, mesons enter as fields.
- As $m_b, m_c \geq \lambda_{QCD} \geq m_u, m_d, m_s$ we look at the limit in which heavy mesons have infinite mass and mass of light mesons is 0.
- Heavy meson chiral perturbation theory can be used to describe the decays of heavy mesons in to heavy or light mesons, if light mesons do not carry large momenta.

HMχPT - fields

Heavy mesons form doublets (spin and flavour symmetry):

$$H = \frac{1}{2}(1 + v \cdot \gamma)[P^*_\mu \gamma^\mu - P\gamma_5] \qquad S = \frac{1}{2}(1 + v \cdot \gamma)[D^*_\mu \gamma^\mu \gamma_5 - D]$$

Light mesons form octet:

$$\Pi = \begin{pmatrix} \pi^0/\sqrt{2} + \eta_8/\sqrt{6} & \pi^+ & K^+ \\ \pi^- & -\pi^0/\sqrt{2} + \eta_8/\sqrt{6} & K^0 \\ K^- & \bar{K}^0 & -2\eta_8/\sqrt{6} \end{pmatrix}$$

HMχPT - the Lagrangian

$$\mathcal{L}_s = \frac{f^2}{8} Tr[\partial_\mu \Sigma \partial^\mu \Sigma^\dagger] + \frac{f^2 \lambda_0}{4} Tr[m_q^\xi \Sigma + \Sigma m_q^\xi] -$$

$$Tr[\bar{H}_a (iv \cdot \mathcal{D}_{ab} - \delta_{ab} \Delta_H) H_b] + g Tr[\bar{H}_b H_a \gamma \cdot \mathcal{A}_{ab} \gamma_5]$$

$$+ Tr[\bar{S}_a (iv \cdot \mathcal{D}_{ab}) - \delta_{ab} \Delta_S) S_b] + \tilde{g} Tr[\bar{S}_b S_a \gamma \cdot \mathcal{A}_{ab} \gamma_5] +$$

$$h Tr[\bar{H}_b S_a \gamma \cdot \mathcal{A}_{ab} \gamma_5] \, ,$$

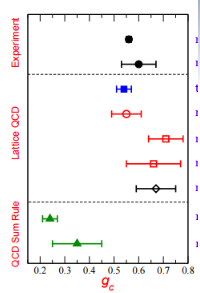
$$\mathcal{L}_\gamma = \frac{\beta e}{4} Tr[\bar{H}_a H_b \sigma^{\mu\nu} F_{\mu\nu} Q_{ba}^\xi] + \frac{\beta' e}{4} Tr[\bar{S}_a S_b \sigma^{\mu\nu} F_{\mu\nu} Q_{ba}^\xi]$$

$$+ \frac{\tilde{\beta} e}{4} Tr[\bar{H}_a S_b \sigma^{\mu\nu} F_{\mu\nu} Q_{ba}^\xi] + h.c. \, ,$$

HMχPT - coupling constants

- strong coupling constants (g, $\tilde{g}$, h)
  - coupling between two parity negative heavy mesons and a light meson - g
  - coupling between two parity positive heavy mesons and a light meson - $\tilde{g}$
  - coupling between parity positive heavy mesons, parity negative heavy meson and a light meson - h
- radiative coupling constants (β, $\tilde{\beta}$, β')
  - coupling between two parity negative heavy mesons and a photon - β
  - coupling between two parity positive heavy mesons and a photon - β'
  - coupling between parity positive heavy mesons, parity negative heavy meson and a photon - $\tilde{\beta}$

Strong coupling constants



- coupling constant g $\rightarrow 0.54(3)(^{+2}_{-4})$ [1]
- coupling constant $\tilde{g} \rightarrow -0.122(8)(6)$ [2]

  (in agreement with other studies)
- coupling constant $h \rightarrow 0.84(3)(2)$ [2]

  (phenomenology: 0.5 - 0.7, except [3] where h=0.88)

[1] D. Becirevic, F. Sanfilippo, Phys. Lett. B 721 (2013)

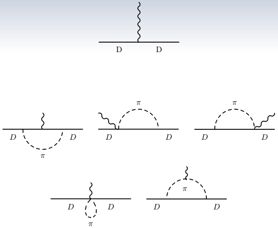
[2] B. Blossier et. al. EPJC 75 (2015)

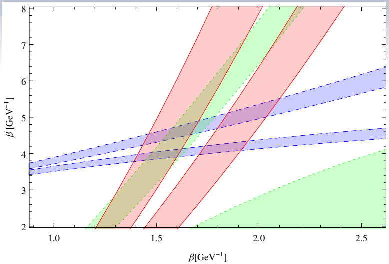
[3] Z. G. Wang, S. L. Wan, PRD 73 (2006)

Radiative coupling constants

decay mode	$\bar{c}u$	$\bar{c}d$	$\bar{c}s$
1^-	$\Gamma_t < 2.1\,\text{MeV}$	$\Gamma_t = (83.4 \pm 1.8)\,\text{keV}$	$\Gamma_t < 1.9\,\text{MeV}$
$1^- \to 0^-\gamma$	$(38.1 \pm 2.9)\%$	$(1.6 \pm 0.4)\%$	$(94.2 \pm 0.7)\%$
0^+	$\Gamma_t = (267 \pm 40)\,\text{MeV}$	possible state	$\Gamma_t < 3.8\,\text{MeV}$
$0^+ \to 1^-\gamma$	no data		no data
$0^+ \to 0^-\gamma$	forbidden		forbidden
1^+	$\Gamma_t = (27.4 \pm 2.5)\,\text{MeV}$	no state	$\Gamma_t < 3.5\,\text{MeV}$
$1^+ \to 0^+\gamma$	no data		$(3.7^{+5.0}_{-2.4})\%$
$1^+ \to 0^-\gamma$	no data		$(18 \pm 4)\%$
$1^+ \to 1^-\gamma$	no data		$< 8\%$

Radiative coupling constants

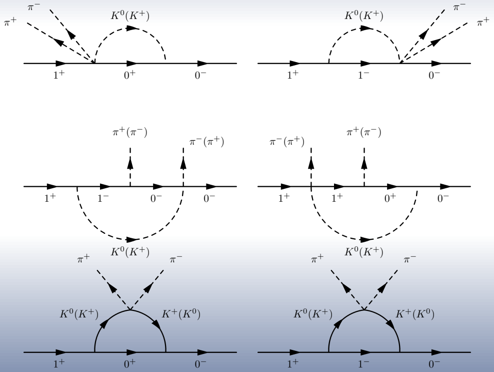




Lousy bounds of $\tilde{\beta}$: (-2,7) GeV^{-1}

$1^+ \to 0^-\pi\pi$ decay modes

Occur only trough chiral loops:

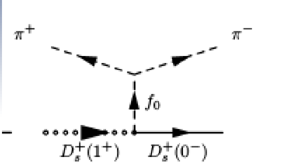


$1^+ \to 0^- \pi\pi$ decay modes

- $\Gamma(D_{s1}(2460)^+ \to D_s^+ \pi^+ \pi^-) = 0.25\,\mathrm{keV}$
- $\Gamma(D_{s1}(2460)^+ \to D_s^+ \pi^0 \pi^0) = 0.15\,\mathrm{keV}$
- $\Gamma(B_{s1}^0 \to B_s^0 \pi^+ \pi^-) = 10^{-3}\,\mathrm{keV}$
- $\Gamma(B_{s1}^0 \to B_s^0 \pi^+ \pi^-) = 0.7 \cdot 10^{-3}\,\mathrm{keV}$

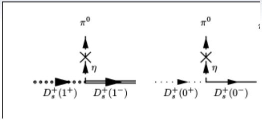
- Chiral loops are proportional to difference of squares of kaon masses
- Small decay width in the case of B_s states is due to small available phase space
- Finite results (no counter-terms needed)

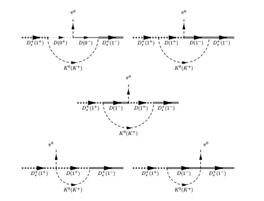
Other approaches to $1^+ \to 0^-\pi\pi$

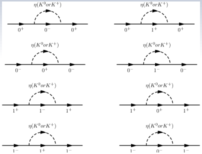


- W. Bardeen et. al. Phys. Rev. D 68, 054024 (2003)
  - $\Gamma(D_{s1}(2460)^+ \to D_s^+\pi^+\pi^-) = 4.2\,\mathrm{keV}$
  - Sigma meson contribution
  - no s contest expected in σ D. Howart at. al., arXiv:1508.05658
- X. Liu et. al. Eur. Phys. J. C 47, 445 (2006)
  - f0(980) contribution
  - $\Gamma(D_{s1}(2460)^+ \to D_s^+\pi^+\pi^-) < 25\,\mathrm{keV}$
- These contributions vanish in HMχPT ($\epsilon \cdot v = 0$)

$1^+ \to 1^-\pi$ and $0^+ \to 0^-\pi$ decays







- Counter-terms are present
- We use the calculated $\Gamma(D_{s1}(2460)^+ \to D_s^+\pi^+\pi^-)$ and experimentally measured ratio between $\Gamma(D_{s1}(2460)^+ \to D_s^+\pi^+\pi^-)$ and $\Gamma(D_{s1}(2460)^+ \to D_s^{*+}\pi^0)$ to extract counter-terms
- Calculated counter-terms are used to predict $\Gamma(B_{s1} \to B_s^*\pi)$ and $\Gamma(B_{s0}^* \to B_s\pi)$ decay widths

Overview

method	$\Gamma(B_{s0}^{*0} \to B_s \pi^0)$ [keV]	$\Gamma(B_{s1}^{0} \to B_s^* \pi^0)$ [keV]	$\Gamma(B_{s1}^{0} \to B_s \pi \pi)$ [keV]
molecule picture	46.7	50.1	
molecule picture	0.8 ± 0.8	1.8 ± 1.8	
heavy quark and chiral symmetry	21.5	21.5	≈ 0.05
heavy chiral unitary approach	7.92	10.36	
$^3P_0$ model	35	38	
light cone sum rules	7.92	10.36	
chiral loop corrections (this work)			
$h = 0.79 - 0.89$	< 55	< 50	≈ 0.001
$h = 0.56$	$2 - 210$	$2 - 195$	≈ 0.001

- The contributions of loops is large (can not be ignored)
- Results are very sensitive to h (large leg corrections)
- More data is needed to see what is actually going on

Conclusions

- More input would be welcome:
  - total decay widths of D_s positive parity states
  - detection of B_s positive parity states and their decay channels
  - lattice results on radiative coupling constants and h extracted form the B_s states
- Simultaneous fit of counter terms and coupling constant h