

# LIFETIME PATTERN OF HEAVY HADRONS

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B. Guberina, B.M., H. Štefančić :

*Enhancement of preasymptotic effects in inclusive  
beauty decays, Phys. Lett. B 469 (1999) 253*

*Lifetime-difference pattern of heavy hadrons  
Phys. Lett. B 484 (2000) 43*

■ DECAY RATE OF A HEAVY HADRON :

$$\begin{aligned}\Gamma(H_Q \rightarrow f) &= \frac{G_F^2 m_Q^5}{192\pi^3} |V|^2 \frac{1}{2M_{H_b}} \{ c_{\bar{Q}Q}^f \langle H_Q | \bar{Q}Q | H_Q \rangle \\ &+ c_G^f \frac{\langle H_Q | \bar{Q} g \sigma_{\mu\nu} G^{\mu\nu} Q | H_Q \rangle}{m_Q^2} \\ &+ \sum_i (c_{4q}^f)_i \frac{\langle H_Q | \bar{Q} \Gamma_i Q \bar{q} \Gamma'_i q | H_Q \rangle}{m_Q^3} + \dots \}\end{aligned}$$

$\mathcal{O}(1/m_Q^2)$ :

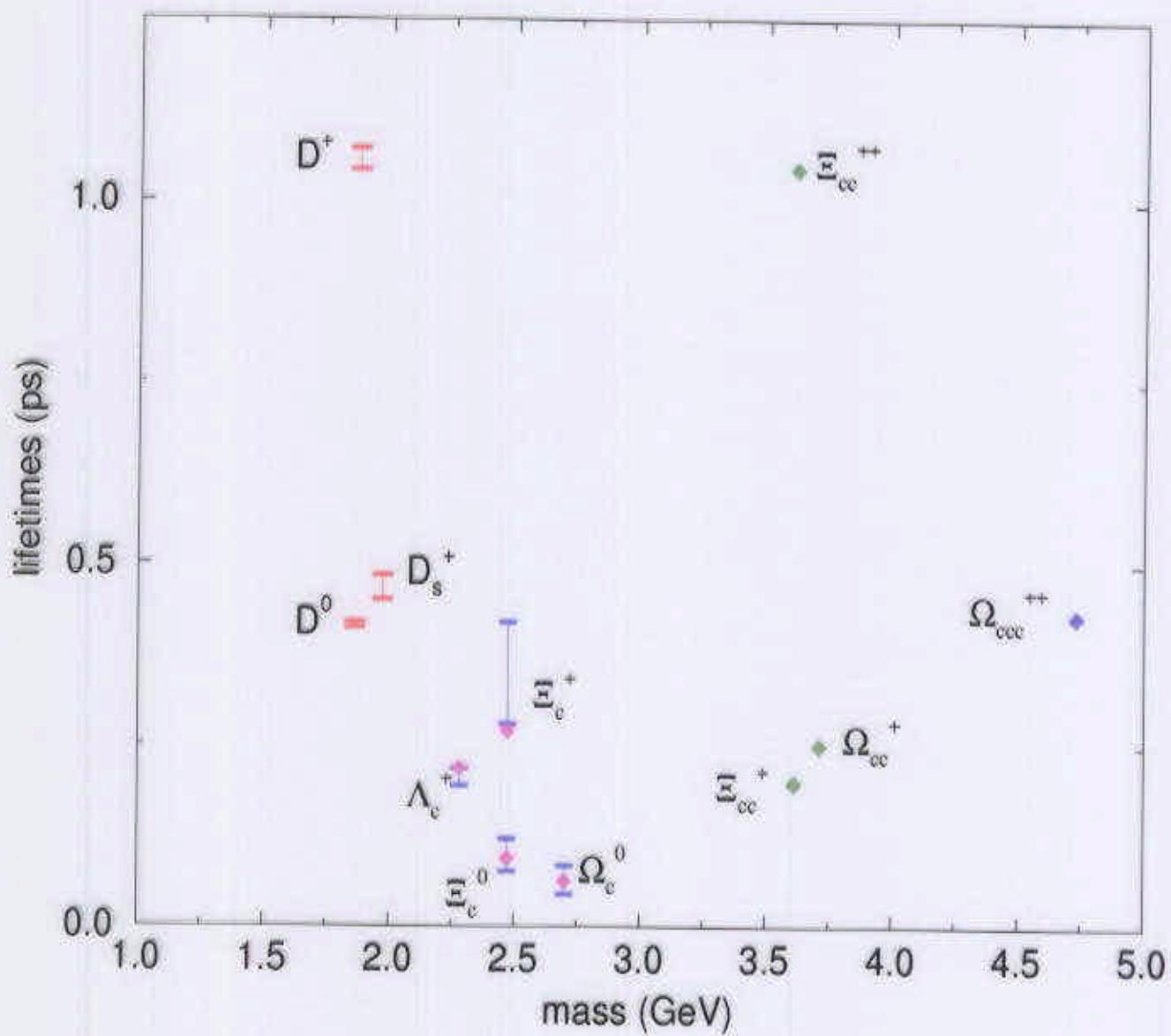
$$\begin{aligned}\frac{1}{2M_{H_Q}} \langle H_Q | \bar{Q}Q | H_Q \rangle &= \\ \left[ 1 + \frac{1}{2m_Q^2} (-\mu_\pi^2(H_Q) + \mu_G^2(H_Q)) + \mathcal{O}\left(\frac{1}{m_Q^3}\right) \right] I_{\bar{Q}Q} \left( \frac{m_q}{m_Q} \right)\end{aligned}$$

$\mathcal{O}(1/m_Q^3)$ :

matrix elements of four-quark operators

- positive/negative Pauli interference
- weak exchange

- ▶ four-quark contributions of the order  $\mathcal{O}(1/m_c^3)$  are crucial to explain the lifetime diversity among charmed hadrons



EXP: Particle Data Group

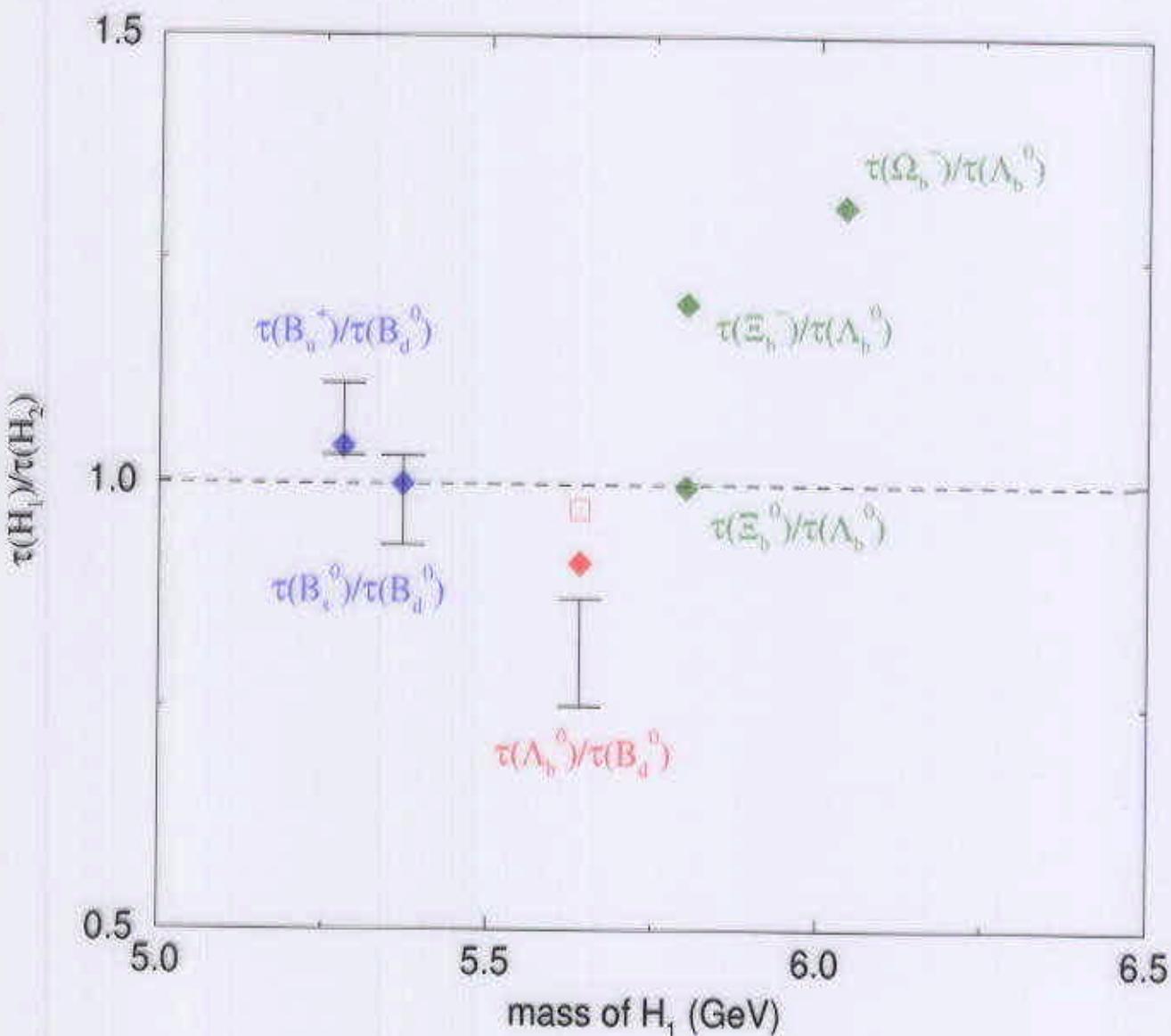
TH:

c-mesons - B. Guberina, S. Nussinov, R. Peccei, R. Rückl, Phys. Lett. B89 (1979) 261

c-baryons - B. Guberina, B. M., Eur. Phys. J. C2 (1998) 697

cc(c)-baryons - B. Guberina, B.M., H.Štefančić, Eur. Phys. J. C9 (1999) 213; ibidem C13 (2000) 551

- ▶ although strongly suppressed by a factor  $1/m_b^3$ , four-quark contributions are crucial to explain the lifetime differences between **beauty hadrons**
- enhancement of four-quark contributions in beauty baryon decays



EXP: Particle Data Group

TH:

b-mesons: I. Bigi, N. Uraltsev, Phys. Lett. B280 (1992) 271

b-baryons: B. Guberina, B.M., H. Štefančić, Phys. Lett. B (1999) 253

## ► HEAVY MESONS

$D^+(c\bar{d})$ ,  $B^-(b\bar{u})$  - negative Pauli interference  
 $D^0(c\bar{u})$ ,  $B^0(b\bar{d})$  - weak exchange

- isolation of the effects of four-quark operators:

$$\Gamma(D^+) - \Gamma(D^0) = \frac{G_F^2 m_c^2}{4\pi} |V_{cs}|^2 |V_{ud}|^2 \times \\ [\langle D^+ | \mathcal{L}_{\text{PI}}^{cd} | D^+ \rangle - \langle D^0 | \mathcal{L}_{\text{exc}}^{cu} | D^0 \rangle]$$

$$\Gamma(B^-) - \Gamma(B^0) = \frac{G_F^2 m_b^2}{4\pi} |V_{cb}|^2 |V_{ud}|^2 \times \\ [\langle B^- | \mathcal{L}_{\text{PI}}^{bu} | B^- \rangle - \langle B^0 | \mathcal{L}_{\text{exc}}^{bd} | B^0 \rangle]$$

- assuming the isospin symmetry ( $u \leftrightarrow d$ ) and HQS ( $b \leftrightarrow c$ ):

$$R^{BD} = \frac{\Gamma(B^-) - \Gamma(B^0)}{\Gamma(D^+) - \Gamma(D^0)} = \frac{m_b^2 |V_{cb}|^2}{m_c^2 |V_{cs}|^2} [1 + \mathcal{O}(1/m_{b,c})]$$

$$R^{BC} = 0.020 \pm 0.007 \leftrightarrow R_{\text{exp}}^{BC} = 0.030 \pm 0.011$$

$$m_c = 1.25 \pm 0.1 \text{ GeV}$$

PDG, lifetimes

$$m_b = 4.59 \pm 0.08 \text{ GeV}$$

## ► HEAVY BARYONS

$\Xi_c^+(cus)$ ,  $\Xi_b^-(bds)$  - negative Pauli interference  
 $\Xi_c^0(cds)$ ,  $\Xi_b^0(bus)$  - weak exchange

+ different NL and SL contributions from the operators involving the s-quark

- isolation of the effects of four-quark operators (in a manner that contributions from the operators containing the s-quark field cancel):

$$\begin{aligned}\Gamma(\Xi_c^+) - \Gamma(\Xi_c^0) &= \frac{G_F^2 m_c^2}{4\pi} |V_{cs}|^2 |V_{ud}|^2 \times \\ &\quad [\langle \Xi_c^+ | \mathcal{L}_{\text{PI}}^{cu} | \Xi_c^+ \rangle - \langle \Xi_c^0 | \mathcal{L}_{\text{exc}}^{cd} | \Xi_c^0 \rangle] \\ \Gamma(\Xi_b^-) - \Gamma(\Xi_b^0) &= \frac{G_F^2 m_b^2}{4\pi} |V_{cb}|^2 |V_{ud}|^2 \times \\ &\quad [\langle \Xi_b^- | \mathcal{L}_{\text{PI}}^{bd} | \Xi_b^- \rangle - \langle \Xi_b^0 | \mathcal{L}_{\text{exc}}^{bu} | \Xi_b^0 \rangle]\end{aligned}$$

-assuming the isospin symmetry ( $u \leftrightarrow d$ ) and HQS ( $b \leftrightarrow c$ ):

$$R^{bc} = \frac{\Gamma(\Xi_b^-) - \Gamma(\Xi_b^0)}{\Gamma(\Xi_c^+) - \Gamma(\Xi_c^0)} = \frac{m_b^2 |V_{cb}|^2}{m_c^2 |V_{cs}|^2} [1 + \mathcal{O}(1/m_{b,c})]$$

■ SAME FORMALISM OF c AND b DECAYS  
- POSSIBLE CONNECTIONS ?

► LIFETIME DIFFERENCES BETWEEN BEAUTY HYPERONS  $\Lambda_b$ ,  $\Xi_b^-$  AND  $\Xi_b^0$

M. Voloshin, Phys.Rept. 320 (1999) 275

- model-independent determination
- $SU(3)_f$  symmetry and heavy-quark symmetry (HQS)
- extraction of values of four-quark operators from the experimental data on charmed baryons  $\xrightarrow{HQS}$  BEAUTY SECTOR

► LIFETIMES OF BEAUTY ( $\Lambda_b$ ,  $\Xi_b$ ) HYPERONS and  $\Omega_b$

B.Guberina, B.M., H. Štefančić, Phys. Lett. B469 (1999) 253

- moderate model-dependent determination
- $SU(3)_f$  symmetry and heavy-quark symmetry (HQS)
- non-relativistic quark model:  $\langle$ four – quark operators $\rangle \sim |\Psi_{\Lambda_b}(0)|^2$
- baryon wave function parametrization:  $|\Psi_{\Lambda_b}(0)|^2 \sim (F_B^{eff})^2$
- $(F_B^{eff})^2$  is extracted from the lifetime differences between heavy baryons:  $F_B^{eff} = (0.441 \pm 0.026) \text{ GeV} \rightarrow$  ENHANCEMENT OF THE FOUR-QUARK CONTRIBUTIONS

► TO BE COMPARED:

- B-meson decay constant  $f_B = 0.16\text{--}0.17 \text{ GeV}$

$$|\Psi_{\Lambda_b}(0)|^2 / |\Psi_{\Lambda_b}(0)|^2_{|f_B} \sim 7$$

- SAME FORMALISM OF c AND b DECAYS  
- POSSIBLE CONNECTIONS ?

► LIFETIME PATTERN OF HEAVY HADRONS

B. Guberina, B.M., H. Štefančič, Phys. Lett. B 484 (2000) 43

- model-independent analysis
- $SU(2)_f$  symmetry and heavy-quark symmetry (HQS)
- we relate heavy hadrons affected by the same type of four-quark contributions
- approximations:
  - only leading Cabibbo modes
  - mass corrections are neglected

## ► DOUBLY HEAVY BARYONS

$\Xi_{cc}^{++}(ccu)$ ,  $\Xi_{bb}^-(bbd)$  - negative Pauli interference  
 $\Xi_{cc}^+(ccd)$ ,  $\Xi_{bb}^0(bbu)$  - weak exchange

- no Cabibbo-leading SL contributions
- isolation of the effects of four-quark operators:

$$\begin{aligned}\Gamma(\Xi_{cc}^{++}) - \Gamma(\Xi_{cc}^+) &= \frac{G_F^2 m_c^2}{4\pi} |V_{cs}|^2 |V_{ud}|^2 \times \\ &\quad [\langle \Xi_{cc}^{++} | \mathcal{L}_{\text{PI}}^{cu} | \Xi_{cc}^{++} \rangle - \langle \Xi_{cc}^+ | \mathcal{L}_{\text{exc}}^{cd} | \Xi_{cc}^+ \rangle] \\ \Gamma(\Xi_{bb}^-) - \Gamma(\Xi_{bb}^0) &= \frac{G_F^2 m_b^2}{4\pi} |V_{cb}|^2 |V_{ud}|^2 \times \\ &\quad [\langle \Xi_{bb}^- | \mathcal{L}_{\text{PI}}^{bd} | \Xi_{bb}^- \rangle - \langle \Xi_{bb}^0 | \mathcal{L}_{\text{exc}}^{bu} | \Xi_{bb}^0 \rangle]\end{aligned}$$

- assuming the isospin symmetry ( $u \leftrightarrow d$ ) and HQS ( $b \leftrightarrow c$ ):

$$R^{bbcc} = \frac{\Gamma(\Xi_{bb}^-) - \Gamma(\Xi_{bb}^0)}{\Gamma(\Xi_{cc}^{++}) - \Gamma(\Xi_{cc}^+)} = \frac{m_b^2 |V_{cb}|^2}{m_c^2 |V_{cs}|^2} [1 + \mathcal{O}(1/m_{b,c})]$$

- using theoretical predictions for doubly-charmed baryon lifetimes:  $(\Gamma(\Xi_{cc}^{++}) = 0.95 \text{ ps}^{-1}, \Gamma(\Xi_{cc}^+) = 5 \text{ ps}^{-1}$  - B. Guberina, B.M., H. Štefančić, Eur. Phys. C9 (1999) 213 ):

$$\Gamma(\Xi_{bb}^-) - \Gamma(\Xi_{bb}^0) = -0.073 \text{ ps}^{-1}$$

$$R^{bc} = \frac{\Gamma(\Xi_b^-) - \Gamma(\Xi_b^0)}{\Gamma(\Xi_c^+) - \Gamma(\Xi_c^0)} = \frac{m_b^2 |V_{cb}|^2}{m_c^2 |V_{cs}|^2} [1 + \mathcal{O}(1/m_{b,c})]$$

▷ test of the model-dependent predictions → 12%

$$(R_{TH}^{bc})^{approx}/R^{bc} = 0.88$$

$$R_{TH}^{bc}/R^{bc} = 0.79$$

-order of neglected corrections: ~ 10%

▷ PREDICTION:

-using measured lifetimes of singly-charmed baryons  $\Xi_c^+$  and  $\Xi_c^0$ :

$$\Gamma(\Xi_b^-) - \Gamma(\Xi_b^0) = -(0.14 \pm 0.06) \text{ ps}^{-1}$$

-to be compared with

i) model-independent prediction ( $SU(3)_f$  and HQS)

$$\Gamma(\Xi_b^-) - \Gamma(\Xi_b^0) = -(0.11 \pm 0.03) \text{ ps}^{-1}$$

ii) moderate model-dependent prediction  
(figure !)

$$\Gamma(\Xi_b^-) - \Gamma(\Xi_b^0) = -(0.094) \text{ ps}^{-1}$$

## ■ CONCLUSIONS

- universal behaviour in the decays of heavy hadrons:

$$\frac{\Gamma(B^-) - \Gamma(B^0)}{\Gamma(D^+) - \Gamma(D^0)} = \frac{\Gamma(\Xi_b^-) - \Gamma(\Xi_b^0)}{\Gamma(\Xi_c^+) - \Gamma(\Xi_c^0)} = \frac{\Gamma(\Xi_{bb}^-) - \Gamma(\Xi_{bb}^0)}{\Gamma(\Xi_{cc}^{++}) - \Gamma(\Xi_{cc}^+)} \\ = \frac{m_b^2 |V_{cb}|^2}{m_c^2 |V_{cs}|^2}$$

### BENEFITS:

- HQSS is applied first at  $\mathcal{O}(1/m_{b,c}^3)$  level  $\Rightarrow$  sensitivity to the choice of heavy quark masses is significantly reduced
- by knowing some decay rates, one can calculate or give constraints on some other rates
- by knowing some decay rate from the experiment, one can test the findings of the theory in a model-independent fashion
- PREDICTIONS  $\Rightarrow$  four-quark operators can account for the greatest part of decay rate differences between heavy hadrons