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# Preasymptotic effects in beauty decays

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## Abstract

Large preasymptotic effects in beauty decays have been found using heavy-quark and SU(3) symmetry, as well as experimental data on charmed hyperons. Contrary to rather uniform beauty-meson lifetimes, a much larger spread of beauty-baryon lifetimes is predicted. However, it is highly unlikely that, theoretically, the $\tau(\Lambda_b)/\tau(B_d^0)$ ratio, which at present deviates more than $1\sigma$ from the experimental result, can be lowered below 0.9.

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# PREASYMPTOTIC EFFECTS IN BEAUTY DECAYS*

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Large preasymptotic effects in beauty decays have been found using heavy-quark and SU(3) symmetry, as well as experimental data on charmed hyperons. Contrary to rather uniform beauty-meson lifetimes, a much larger spread of beauty-baryon lifetimes is predicted. However, it is highly unlikely that, theoretically, the $\tau(\Lambda_b)/\tau(B_d^0)$ ratio, which at present deviates more than $1\sigma$ from the experimental result, can be lowered below 0.9.

The saga of beauty never comes to an end[1]. During the last decade the general belief has been that decays of beauty quarks should be very well described theoretically in the framework of the Operator Product Expansion (OPE) and the Heavy-Quark Effective Theory (HQET). The mass of the beauty quark, being of the order of 5 GeV, appears to be heavy enough to ensure the fast convergence of the $1/m_b$ expansion. The diversity of lifetimes of 'beautiful' mesons and baryons is expected first at the subleading level in the $1/m_b$ expansion. The lifetimes of beauty mesons follow this simple theoretical prediction within $5-10\%$ in the $m_b \to \infty$ limit:

$$\tau(B^+) = \tau(B_d^0) = \tau(B_s^0)\,. \tag{1}$$

The only measured baryon lifetime $\tau(\Lambda_b)$ appears to be smaller by $15-25\%$; experimentally, it follows that

$$\frac{\tau(\Lambda_b)}{\tau(B_d^0)} = 0.81 \pm 0.05 \; (\mathrm{PDG})\,, \tag{2}$$

while the theoretical value is about 0.98. This discrepancy raises doubt that the quark-hadron duality might be, *horribile dictu*, severely flawed.

The rate of the beauty-hadron decay is given as a sum over matrix elements of D-dimensional operators. The sum starts with the operator of dimension D=3 and shows the fast convergence in the $1/m_b$ expansion. First corrections proportional to the operator of D=5 are controllable and by taking them into account we obtain the difference of $2-3\%$ in the lifetimes of beauty hadrons. Therefore, the only hope to come closer to the ratio (2)

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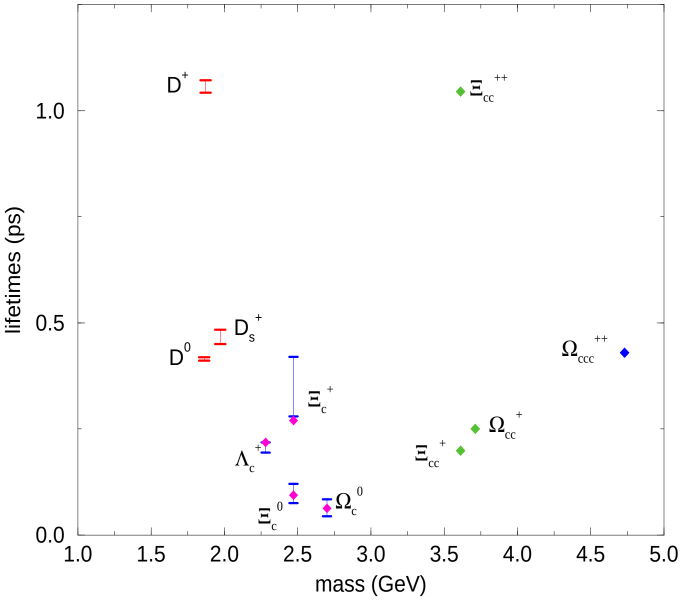

Figure 1. Experimental (with error bars) and theoretical (filled diamonds - calculated in [4] and [5]) results for lifetimes of weakly decaying charmed hadrons.

is to look for the possible larger contributions coming from the operators of dimension D=6 or higher. These operators are known to play an important role in charmed-meson decays[2] and their effects are even more pronounced in charmed-baryon decays[3]. Recently, the analysis of singly charmed baryons[4] has been extended to doubly charmed baryons[5,6] (Fig.1), where the idea of 'meson-like' baryons, in which heavy quarks form a diquark, was applied. A possible physical interpretation of this philosophy is the existence of hadronic supersymmetry[7], which appears whenever the diquark is physically realizable.

However, the calculation of the contribution of D=6 operators suffers from the strong model-dependence in the evaluation of their matrix elements. Recently, Voloshin[8] has proposed the way of reducing the model dependence. His main assumption is that, owing to SU(3)-flavor and heavy-quark symmetry, the matrix elements of four-quark operators extracted from experimental data on charmed hyperons can be used for calculation in the beauty sector, provided that they are normalized at the low energy scale $\mu \sim 1$ GeV. The result of these assumptions is that lifetime differences between beauty hyperons

$(\Lambda_b, \Xi_b)$ can be expressed through the (measured) lifetime differences between charmed hyperons $(\Lambda_c, \Xi_c)$ without invoking an explicit model-dependent calculation of four-quark operators. The possible uncertainty of this approach is of the order $\mathcal{O}(m_c^2/m_b^2) \sim 0.1$.

We have extended[9] Voloshin's analysis by introducing a rather modest model dependence in order to obtain more predictive power, i.e., the lifetimes of the $(\Lambda_b, \Xi_b)$ hyperon triplet and the lifetime of $\Omega_b$. Basically, we express the decay rates in terms of the baryon wave function squared $|\Psi(0)|^2$, which parametrizes the four-quark operator contributions and is usually given by the nonrelativistic relation $|\Psi(0)|^2 \sim f_B^2$, $f_B$ being the meson decay constant. We use Voloshin's approach to determine the value of the $|\Psi(0)|^2$. From the lifetime differences between members of beauty hyperons we are able to extract an effective decay constant, $|\Psi(0)|^2 \sim (F_B^{eff})^2$,

$$F_B^{eff} = (0.441 \pm 0.026)\,\mathrm{GeV}\,. \tag{3}$$

It is instructive to compare this value with the value of $f_B$, $f_B = 0.16 - 0.17\,\mathrm{GeV}$, and then the ratio of the baryon over meson wave function, which is, according to our model, about 7-8 times larger than when we apply the nonrelativistic model: $|\Psi_{\Lambda_b}(0)|^2/|\Psi_B(0)|^2 \sim 4.2$. This effectively means that, in our approach, four-quark contributions in beauty-baryon lifetimes are enhanced by almost an order of magnitude.

Owing to ambiguities in the determination of the bottom quark mass, we concentrate mainly on the lifetime ratios. We follow the philosophy of using the running quark mass $\overline{m}_b$ to avoid the renormalon ambiguities and therefore have to choose $\overline{m}_b(1\,\mathrm{GeV}) = 4.7\,\mathrm{GeV}$.

The predicted hierarchy in the sector of beauty baryons is then

$$\tau(\Lambda_b) \simeq \tau(\Xi_b^0) < \tau(\Xi_b^-) < \tau(\Omega_b)\,, \tag{4}$$

and the obtained lifetime ratios are

$$\tau(\Xi_b^-)/\tau(\Lambda_b) \simeq 1.20\,, \qquad \tau(\Omega_b)/\tau(\Lambda_b) \simeq 1.30\,. \tag{5}$$

These ratios are much larger than those predicted by the standard nonrelativistic model.

Let us now briefly discuss the problem of the $\tau(\Lambda_b)$ over $\tau(B)$ ratio. The problem is the clear discrepancy between the experimental ratio (2) and the theory which gives

$$\tau(\Lambda_b)/\tau(B_d^0) = 0.97 + \mathcal{O}(1/m_b^3) \tag{6}$$

just by taking the first, $\mathcal{O}(1/m_b^2)$ corrections into account. Owing to the fast convergence of the $1/m_b$ expansion and because the vacuum saturation approximation for mesons works rather well, it seems that the decay rate of the $B$-meson cannot be significantly smaller to lower the $\tau(\Lambda_b)/\tau(B)$ ratio. The only hope then persists in the enlargement of four-quark contributions in the $\Lambda_b$-decay, but these effects also cannot be pushed over some limit. So the question is: can we accommodate the theoretical prediction on the $\tau(\Lambda_b)/\tau(B_d^0)$ ratio to the experimental result, using our enhancement of the four-quark contributions in the $\Lambda_b$-decay ?

Clearly, we need the smaller $m_b$ to obtain the larger preasymptotic effects, but there is a competition between the $\mathcal{O}(1/m_b^2)$ effects in mesons and the $\mathcal{O}(1/m_b^3)$ effects in $\Lambda_b$. The net result is then the stable $\tau(\Lambda_b)/\tau(B)$ ratio:

$$\tau(\Lambda_b)/\tau(B_d^0) \sim 0.90 \pm 0.01 \qquad \text{for} \qquad m_b = 4.4 - 4.8\,\text{GeV}\,. \tag{7}$$

We have also checked the result against the deviation from the valence quark approximation (VQA)[10], which equals the deviation of the $\overline{B}$-parameter from one:

$$x = -\overline{B}y\,. \tag{8}$$

Here $x \sim \langle \overline{b}\Gamma_\mu b\,\overline{q}\Gamma^\mu q\rangle$ and $y \sim \langle \overline{b}^i\Gamma_\mu b^j\,\overline{q}^j\Gamma^\mu q^i\rangle$, $\Gamma_\mu = (V-A)_\mu$, and $q$'s denote light quarks in a baryon.

We have extracted this ratio to be $|x/y| \approx 1.8 \pm 1.0$ at $\mu = 1\,\text{GeV}$, which is consistent with the result[10] of Voloshin. Owing to the large error in its determination, it is difficult to give a definite conclusion about the validity of the VQA and therefore we prefer to use $\overline{B} = 1$ in our predictions. However, it is also clear that the VQA cannot be generally valid, because of the fact that $y$ is a $\mu$ dependent quantity, while $x$ is not, and the result that $|x/y|$ is significantly larger than 1 might prove at the end to be both correct and fundamental. But, even if the VQA is heavily broken by almost 100%, the $\tau(\Lambda_b)/\tau(B)$ ratio *cannot* be lowered below 0.9 value.

To conclude, although there might still be some place for nonfactorizable contributions in mesons to play some role, it is highly unlikely that the lifetimes of $\Lambda_b$ and the $B$-meson can be split by more than 10% (7). To reach the experimental value for the $\tau(\Lambda_b)/\tau(B)$ ratio (2) would require $F_B^{eff}|_{\text{fit}} \sim 0.720\,\text{GeV}$, which can hardly be accommodated in the present theory. Should future data maintain the $\tau(\Lambda_b)/\tau(B)$ ratio well below 0.9, that would indicate the violation of some of underlying concepts of the present theory, such as the quark-hadron duality. One of the tests will also be the experimental check of the predicted spread of beauty-baryon lifetimes of the order of 20% in the $\tau(\Xi_b^-)/\tau(\Lambda_b)$ ratio and of 30% in the $\tau(\Omega_b)/\tau(\Lambda_b)$ ratio (Fig.2).

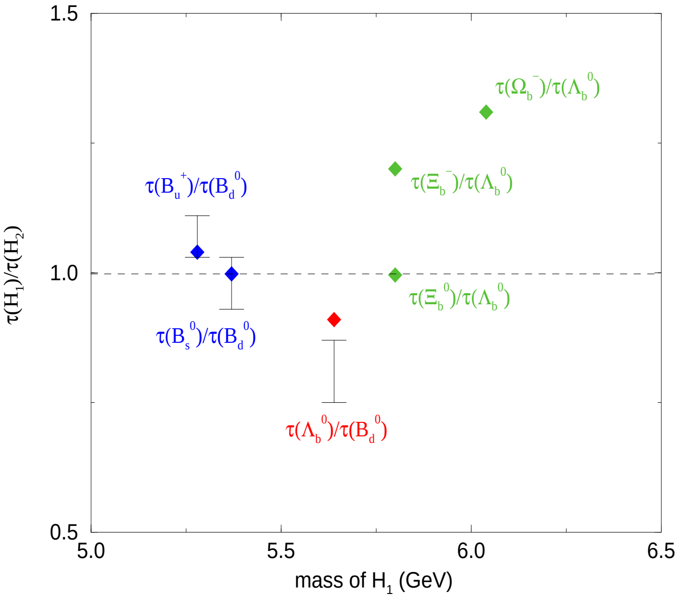

Figure 2. Experimental (with error bars) and theoretical (filled diamonds) results for ratios of lifetimes of beauty hadrons. Meson lifetimes are obtained using $f_b = 160\,\mathrm{GeV}$.

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## References

1. I Bigi, hep-ph/0001003, these Proceedings
2. B Guberina, S Nussinov, R Peccei and R Rückl, *Phys. Lett.* B **89**, 111 (1979); N Bilić, B Guberina and J Trampetić, *Nucl. Phys.* B **248**, 261 (1984); M Shifman, M B Voloshin, *Sov. J. Nucl. Phys.* **41**, 120 (1985).
3. M Shifman, M B Voloshin, *JETP* **64**, 698 (1986); B Guberina, R Rückl, and J Trampetić, *Z. Phys.* C **33**, 297 (1986).
4. B Guberina, B Melić, *Eur. Phys. J. C* **2**, 697 (1998).

5. B Guberina, B Melić and H Štefančić, *Eur. Phys. J. C* **9**, 213 (1999); *ibidem: Erratum*(to appear).
6. V V Kiselev, A K Likhoded and A I Onishchenko, *Phys. Rev.* D **60**, 014007 (1999).
7. D B Lichtenberg, hep-ph/9912280.
8. M B Voloshin, hep-ph/9901445.
9. B Guberina, B Melić and H Štefančić, *Phys. Lett.* B **469**, 253 (1999).
10. M B Voloshin, hep-ph/9908455.