Proceedings of the VIIIth International Workshop on Heavy Quarks and Leptons HQL06

October 2006

Deutsches Museum, Munich

Editors
S. Recksiegel, A. Hoang, S. Paul

Organized by the Physics Department of the Technical University of Munich
and the Max-Planck Institute for Physics, Munich

Lifetimes and oscillations of heavy mesons

Alexander Lenz
Institut für theoretische Physik
Universität Regensburg
D-93040 Regensburg - Germany

1 Abstract

We review the theoretical status of the lifetime ratios τ_{B^+}/τ_{B_d} and τ_{B_s}/τ_{B_d} and of the mixing quantities ΔM_s, $\Delta\Gamma_s$ and ϕ_s. We show that the ratio $\Delta\Gamma_s/\Delta M_s$ can be determined with almost no non-perturbative uncertainties. Finally we explain how this precise determination of the standard model values can be used to find possible new physics contributions in ΔM_s, $\Delta\Gamma_s$, $\Delta\Gamma_s/\Delta M_s$ and a^s_{fs}. Combining the latest experimental bounds on these quantities one already gets some hints for new physics contributions.

2 Introduction

Inclusive decays (see e.g. [1] or [2] and references therein) and lifetimes of heavy mesons can be calculated within the framework of the so-called heavy quark expansion (HQE) [3,4]. In this approach the decay rate is calculated in an expansion in inverse powers of the heavy b-quark mass.

$$\Gamma = \Gamma_0 + \frac{\Lambda^2}{m_b^2}\Gamma_2 + \frac{\Lambda^3}{m_b^3}\Gamma_3 + \ldots \tag{1}$$

Γ_0 represents the decay of a free heavy b-quark, according to this contribution all b-mesons have the same lifetime. The first correction arises at order $1/m_b^2$, they are due to the kinetic and the chromomagnetic operator. At order $1/m_b^3$ the spectator quark gets involved in the weak annihilation and Pauli interference diagrams [3,5]. This contributions are numerically enhanced by a phase space factor of $16\pi^2$. Each of the Γ_i contains perturbatively calculable Wilson coefficients and non-perturbative parameters, like decay constants or bag parameters. Unfortunately the theoretical predictions for the decay constants vary over a wide range: quenched lattice determinations for f_{B_s} tend to give values of $\mathcal{O}(200)$ MeV, while recent unquenched calculations with 2+1 dynamical light flavors give values around 260 MeV - for a more detailed discussion see [6–8]. Since lifetime differences depend quadratically on the decay constants, going from 200 MeV to 260 MeV results in an increase of 70%. Here clearly theoretical progress is necessary to pin down the error on the decay constants considerably.

In view of several new theoretical and experimental developments we update the numbers present in the literature (see e.g. [9]).

3 Lifetimes

The lifetime ratio of two heavy mesons can be written as

$$\frac{\tau_1}{\tau_2} = 1 + \frac{\Lambda^3}{m_b^3}\left(\Gamma_3^{(0)} + \frac{\alpha_s}{4\pi}\Gamma_3^{(1)} + \ldots\right) + \frac{\Lambda^4}{m_b^4}\left(\Gamma_4^{(0)} + \frac{\alpha_s}{4\pi}\Gamma_4^{(1)} + \ldots\right) + \ldots \tag{2}$$

If one neglects small isospin or SU(3) violating effects one has no $1/m_b^2$ corrections [1] and a deviation of the lifetime ratio from one starts at order $1/m_b^3$.

3.1 τ_{B^+}/τ_{B_d}

The leading term $\Gamma_3^{(0)}$ has been determined in [3, 10]. For a quantitative treatment of the lifetime ratios NLO QCD corrections are mandatory - $\Gamma_3^{(1)}$ has been determined in [11, 12]. Subleading effects of $\mathcal{O}(1/m_b)$ turned out to be negligible [13]. The matrix elements of the arising four-quark operators have been determined in [14]. Using the result from [11]

$$\begin{aligned}
\frac{\tau(B^+)}{\tau(B_d^0)} - 1 \; &= \; \tau(B^+)\,\left[\Gamma(B_d^0) - \Gamma(B^+)\right] \\
&= \; 0.0325\,\frac{\tau(B^+)}{1.653\,\mathrm{ps}}\left(\frac{|V_{cb}|}{0.04}\right)^2\left(\frac{m_b}{4.8\mathrm{GeV}}\right)^2\left(\frac{f_B}{200\mathrm{MeV}}\right)^2 \\
&\quad \Big[(1.0 \pm 0.2)\,B_1 \; + \; (0.1 \pm 0.1)\,B_2 \; - \; (18.4 \pm 0.9)\,\epsilon_1 \; + \; (4.0 \pm 0.2)\,\epsilon_2\Big] + \delta_{1/m}
\end{aligned} \tag{3}$$

one gets with the matrix elements from Becirevic [14] ($B_1 = 1.10 \pm 0.20$; $B_2 = 0.79 \pm 0.10$; $\epsilon_1 = -0.02 \pm 0.02$; $\epsilon_2 = 0.03 \pm 0.01$) and the values $V_{cb} = 0.0415$, $m_b = 4.63$ GeV and $f_B = 216$ MeV [15]:

$$\left[\frac{\tau(B^+)}{\tau(B_d^0)}\right]_{\mathrm{NLO}} \; = \; 1.063 \pm 0.027\,, \tag{4}$$

[1]In the case of $\tau_{\Lambda_b}/\tau_{B_d}$ these effects are expected to be of the order of 5%.

which is in excellent agreement with the experimental number [16, 17]

$$\left[\frac{\tau(B^+)}{\tau(B_d^0)}\right] = 1.071 \pm 0.009\,. \tag{5}$$

From Eq. (3) one clearly sees that a precise knowledge of the color octet bag parameters ϵ_1 and ϵ_2 - these parameters are of order $1/N_c$ - is mandatory since their coefficients are numerically enhanced. Here clearly more work has to be done.

3.2 τ_{B_s}/τ_{B_d}

In the lifetime ratio τ_{B_s}/τ_{B_d} a cancellation of weak annihilation contributions arises, that differ only by small SU(3)-violation effects. One expects a number that is close to one [10, 12, 18, 19]

$$\frac{\tau(B_s)}{\tau(B_d)} = 1.00 \pm 0.01\,. \tag{6}$$

This expectation is confirmed by experiment [17, 20]

$$\frac{\tau(B_s)}{\tau(B_d)} = 0.957 \pm 0.027\,, \tag{7}$$

although more precise experimental numbers would be very desirable.

3.3 $\tau_{B_c^+}$

The lifetime of the doubly heavy meson B_c has been investigated in [21]

$$\tau(B_c) = 0.52^{+0.18}_{-0.12}\,\mathrm{ps}\,. \tag{8}$$

In addition to the b-quark now also the c-charm quark can decay, giving rise to the biggest contribution to the total decay rate. The current experimental number [22]

$$\tau(B_c) = 0.469 \pm 0.027\,\mathrm{ps} \tag{9}$$

agrees nicely with the theoretical prediction, but it has much smaller errors. Here clearly some theoretical improvements are necessary to pin down the error.

4 Mixing Parameters

In this section we briefly investigate the status of the mixing parameters. For a more detailed review we refer the interested reader to [7].
The mixing of the neutral B-mesons is described by the off diagonal elements Γ_{12} and

M_{12} of the mixing matrix. Γ_{12} stems from the absorptive part of the box diagrams - only internal up and charm quarks contribute, while M_{12} stems from the dispersive part of the box diagram, therefore being sensitive to heavy internal particles like the top quark or heavy new physics particles. By diagonalizing the mixing matrix we obtain the physical eigenstates B_H and B_L with defined masses (M_H, M_L) and defined decay rates (Γ_H, Γ_L) in terms of the flavor eigenstates $B_s = (\bar{b}s)$ and $\overline{B}_s = (b\bar{s})$:

$$B_H := p\, B + q\, \overline{B}\,, \qquad B_L := p\, B - q\, \overline{B} \qquad \text{with } |p|^2 + |q|^2 = 1\,. \tag{10}$$

The calculable quantities $|M_{12}|$, $|\Gamma_{12}|$ and $\phi = \arg(-M_{12}/\Gamma_{12})$ can be related to three observables:

- **Mass difference:**

$$\Delta M := M_H - M_L = 2|M_{12}| \left(1 + \frac{1}{8}\frac{|\Gamma_{12}|^2}{|M_{12}|^2}\sin^2\phi + ...\right) \tag{11}$$

  $|M_{12}|$ is due to heavy internal particles in the boxdiagrams like the top-quark or SUSY-particles.

- **Decay rate difference:**

$$\Delta\Gamma := \Gamma_L - \Gamma_H = 2|\Gamma_{12}|\cos\phi \left(1 - \frac{1}{8}\frac{|\Gamma_{12}|^2}{|M_{12}|^2}\sin^2\phi + ...\right) \tag{12}$$

  $|\Gamma_{12}|$ is due to light internal particles: particles, like the up- and the charm-quark. It is therefore very insensitive to new physics contributions.

- **Flavor specific/semileptonic CP asymmetries:**
  A decay $B_q \to f$ is called flavor specific, if the decays $\overline{B}_q \to f$ and $B_q \to \overline{f}$ are forbidden and if no direct CP violation occurs, i.e. $|\langle f|B_q\rangle| = |\langle\overline{f}|\overline{B}_q\rangle|$. Some examples are $B_s \to D_s^- \pi^+$ or $B_q \to X l \nu$ (therefore the name semileptonic CP asymmetry). The flavor specific CP asymmetry is defined as

$$\begin{aligned} a_{fs} &= \frac{\Gamma\left(\overline{B}_q(t) \to f\right) - \Gamma\left(B_q(t) \to \overline{f}\right)}{\Gamma\left(\overline{B}_q(t) \to f\right) + \Gamma\left(B_q(t) \to \overline{f}\right)} = -2\left(\left|\frac{q}{p}\right| - 1\right) \\ &= \mathrm{Im}\frac{\Gamma_{12}}{M_{12}} = \frac{\Delta\Gamma}{\Delta M}\tan\phi\,. \end{aligned}$$

4.1 Mass difference

Calculating the box diagram with internal top quarks one obtains

$$M_{12,q} = \frac{G_F^2}{12\pi^2}(V_{tq}^* V_{tb})^2 M_W^2 S_0(x_t) B_{B_q} f_{B_q}^2 M_{B_q} \hat{\eta}_B \tag{13}$$

The Inami-Lim function $S_0(x_t = \overline{m}_t^2/M_W^2)$ [23] is the result of the box diagram without any gluon corrections. The NLO QCD correction is parameterized by $\hat{\eta}_B \approx 0.84$ [24]. The non-perturbative matrix element of the operator $Q = (\bar{b}q)_{V-A}(\bar{b}q)_{V-A}$ is parameterized by the bag parameter B and the decay constant f_B

$$\langle \overline{B_q}|Q|B_q\rangle = \frac{8}{3} B_{B_q} f_{B_q}^2 M_{B_q} \, . \tag{14}$$

Using the conservative estimate $f_{B_s} = 240 \pm 40$ MeV [7] and the bag parameter B from JLQCD [25] we obtain

$$\Delta M_s = 19.3 \pm 6.4 \pm 1.9 \, \mathrm{ps}^{-1} \tag{15}$$

The first error stems from the uncertainty in f_{B_s} and the second error summarizes the remaining theoretical uncertainties. The determination of ΔM_d is affected by even larger uncertainties because here one has to extrapolate to the small mass of the down-quark. The ratio $\Delta M_s/\Delta M_d$ is theoretically better under control since in the ratio of the non-perturbative parameters many systematic errors cancel.

This year also ΔM_s was measured, leading to the pleasant situation of having very precise experimental numbers at hand [20, 26, 27]

$$\Delta M_d = 0.507 \pm 0.004 \, \mathrm{ps}^{-1} \, , \tag{16}$$

$$\Delta M_s = 17.77 \pm 0.12 \, \mathrm{ps}^{-1} \, . \tag{17}$$

To be able to distinguish possible new physics contributions to ΔM_s from QCD uncertainties much more precise numbers for f_{B_s} are needed.

4.2 Decay rate difference and flavor specific CP asymmetries

In order to determine the decay rate difference of the neutral B-mesons and flavor specific CP asymmetries a precise determination of Γ_{12} is needed. With the help of the HQE Γ_{12} can be written as

$$\Gamma_{12} = \frac{\Lambda^3}{m_b^3}\left(\Gamma_3^{(0)} + \frac{\alpha_s}{4\pi}\Gamma_3^{(1)} + \ldots\right) + \frac{\Lambda^4}{m_b^4}\left(\Gamma_4^{(0)} + \frac{\alpha_s}{4\pi}\Gamma_4^{(1)} + \ldots\right) + \ldots \tag{18}$$

The leading term $\Gamma_3^{(0)}$ was determined in [28]. The numerical and conceptual important NLO-QCD corrections ($\Gamma_3^{(1)}$) were determined in [29–31]. Subleading $1/m$-corrections, i.e. $\Gamma_4^{(0)}$ were calculated in [19, 32] and even the Wilson coefficients of the $1/m^2$-corrections ($\Gamma_5^{(0)}$) were calculated and found to be small [33].

Besides the already known operator Q in the calculation of Γ_{12} three additional operators arise $\tilde{Q}, Q_S$ and $\tilde{Q}_S$. The tilde stands for a color rearrangement and index S corresponds to a S-P Dirac structure instead of the V-A-structure. $Q = \tilde{Q}$ and it can be shown [7, 19, 29] that a certain combination of Q, Q_S and $\tilde{Q}_S$ is suppressed by powers of $1/m_b$ and α_s

$$\tilde{Q} = Q \quad \text{and} \quad R_0 = Q_S + \alpha_1 \tilde{Q}_S + \frac{\alpha_2}{2} Q = \mathcal{O}\left(\frac{1}{m_b}, \alpha_s\right) \tag{19}$$

with $\alpha_i = 1 + \mathcal{O}(\alpha_s)$, for more details see [7]. In the literature [19, 28–31] always $\tilde{Q}_S$ was eliminated - with the help of Eq. (19) - and one was left with the operator basis $\{Q, Q_S\}$, which we call in the following the *old basis*. Working in the old basis one finds several serious drawbacks:

- An almost complete cancellation of the coefficient of the operator Q takes place, while the operator Q_S is dominant. So in the ratio $\Delta\Gamma_s/\Delta M_s$ the only coefficient that is free of non-perturbative uncertainties is numerically negligible.
- The $1/m$ corrections are abnormally large - all contributions have the same sign.
- The α_s-corrections and the remaining μ-dependence is unexpectedly large.

In [7] it was found, that expressing Γ_{12} in terms of the *new basis* $\{Q, \tilde{Q}_S\}$ one gets a result, that is free of the above shortcomings. The change of the basis corresponds to throwing away certain contributions of $\mathcal{O}(\alpha_s^2)$ and $\mathcal{O}(\alpha_s/m_b)$, which is beyond the calculated accuracy. For our new determination of Γ_{12} we also use the $\overline{\text{MS}}$-scheme [34], besides the pole scheme for the b-quark mass. Moreover we sum up logarithms of the form $z \ln z$ - with $z = m_c^2/m_b^2$ - to all orders, following [11] and of course we have to include also subleading CKM-structures to determine a_{fs}, as done in [30, 31].

In the old basis one obtains

$$\Delta\Gamma_s = \left(\frac{f_{B_s}}{240\,\text{MeV}}\right)^2 \left[0.002B + 0.094B'_S - \left(0.033B_{\tilde{R}_2} + 0.019B_{R_0} + 0.005B_R\right)\right], \tag{20}$$

$$\frac{\Delta\Gamma_s}{\Delta M_s} = 10^{-4} \cdot \left[0.9 + 40.9\frac{B'_S}{B} - \left(14.4\frac{B_{\tilde{R}_2}}{B} + 8.5\frac{B_{R_0}}{B} + 2.1\frac{B_R}{B}\right)\right] \tag{21}$$

with

$$\langle \overline{B_s}|Q_S|B_s\rangle = -\frac{5}{3}B'_S f_{B_s}^2 M_{B_s}, \quad B'_X := B_X \frac{M_{B_s}^2}{(\overline{m}_b + \overline{m}_s)^2}. \tag{22}$$

In Eq. (21) we have explicitly shown the dependence on the dominant $1/m$ operators R_2 and R_0 (see [7, 19] for the definition). The remaining power corrections are summarized in the coefficient of B_R. One clearly sees that the cancellation in the coefficient of B leads to the undesirable situation, that the only coefficient in $\Delta\Gamma/\Delta M$ that is free of non-perturbative uncertainties is negligible.

This changes however dramatically if one uses the new basis

$$\Delta\Gamma_s = \left(\frac{f_{B_s}}{240\,\mathrm{MeV}}\right)^2 \left[0.105 B + 0.024 \tilde{B}'_S - \left(0.030 B_{\tilde{R}_2} - 0.006 B_{R_0} + 0.003 B_R\right)\right] \tag{23}$$

$$\frac{\Delta\Gamma_s}{\Delta M_s} = 10^{-4} \cdot \left[46.2 + 10.6 \frac{B'_S}{B} - \left(13.2 \frac{B_{\tilde{R}_2}}{B} - 2.5 \frac{B_{R_0}}{B} + 1.2 \frac{B_R}{B}\right)\right] \tag{24}$$

with

$$\langle \overline{B_s} | \tilde{Q}_S | B_s \rangle = \frac{1}{3} \tilde{B}'_S f_{B_s}^2 M_{B_s} \,. \tag{25}$$

Now the dominant part of $\Delta\Gamma/\Delta M$ can be determined without any hadronic uncertainties!
Using the non-perturbative parameters from [25, 35], we obtain the following final numbers (see [7] for the complete list of the numerical input parameters)

$$\Delta\Gamma_s = (0.096 \pm 0.039)\ \mathrm{ps}^{-1} \Rightarrow \frac{\Delta\Gamma_s}{\Gamma_s} = \Delta\Gamma_s \cdot \tau_{B_d} = 0.147 \pm 0.060 \,, \tag{26}$$

$$a_{fs}^s = (2.06 \pm 0.57) \cdot 10^{-5} \,, \tag{27}$$

$$\frac{\Delta\Gamma_s}{\Delta M_s} = (49.7 \pm 9.4) \cdot 10^{-4} \,, \tag{28}$$

$$\phi_s = 0.0041 \pm 0.0008 = 0.24^\circ \pm 0.04 \,. \tag{29}$$

The composition of the theoretical error of $\Delta\Gamma$ is compared for the use of the old and the new basis in Fig. (1). The by far dominant error comes from the decay constant f_{B_s}, followed by the uncertainty due to the power suppressed operator $\tilde{R}_2$ and the remaining μ-dependence. In this case the theoretical improvement due to the change of basis is somehow limited by the huge uncertainty due to f_{B_s}, which is the same in both bases.

This changes if one looks at the composition of the theoretical error of $\Delta\Gamma/\Delta M$ in Fig. (2). Since now f_{B_s} cancels the dominant error comes from the uncertainty due to the power suppressed operator $\tilde{R}_2$ and the remaining μ-dependence.

One clearly sees that the change of the basis resulted in a considerable reduction of the theoretical error , almost a factor 3 in the case of $\Delta\Gamma_s/\Delta M_s$!
To improve our theoretical knowledge of the mixing quantities further one needs more precise values of the non-perturbative parameters, like the decay constants or the power suppressed operators. If accurate non-perturbative parameters are available one might think about NNLO calculations (α_s^2 or α_s/m_b-corrections) to reduce the remaining μ-dependence.

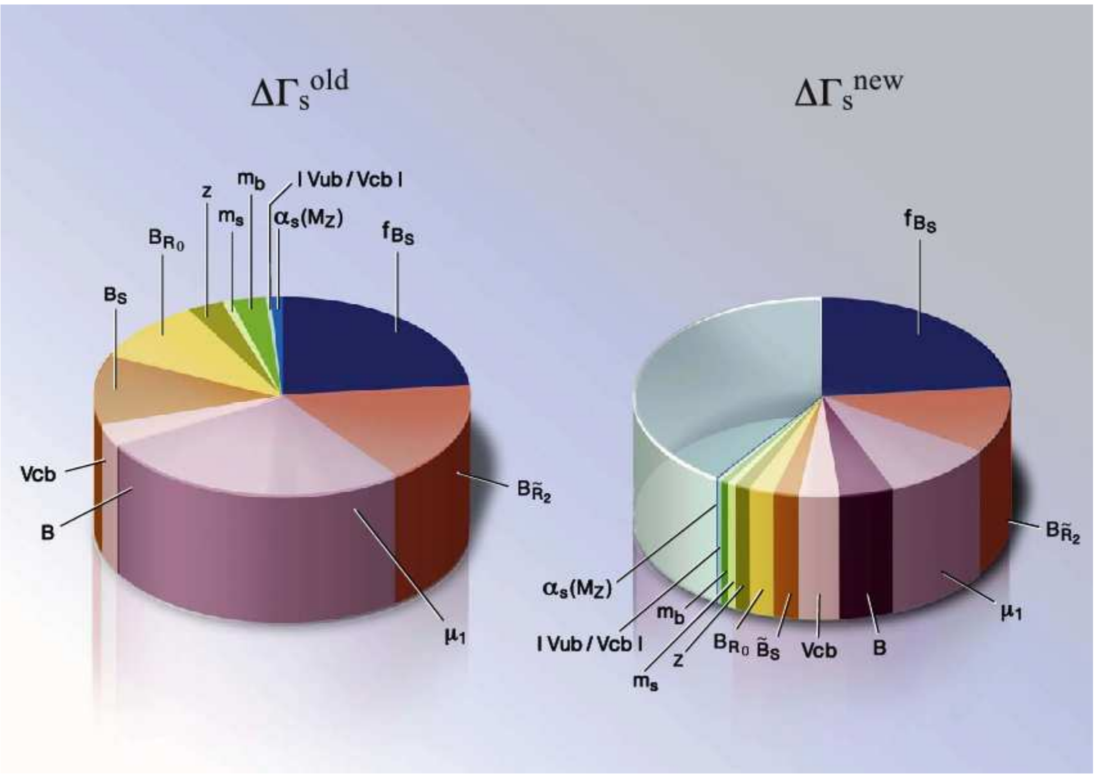

Figure 1: Error budget for the determination of $\Delta\Gamma_s$ in the old and the new basis.

4.3 New Physics

New physics (see e.g. [36]) is expected to have almost no impact on Γ_{12} but it can change M_{12} considerably. Therefore one can write

$$\Gamma_{12,s} = \Gamma_{12,s}^{\rm SM}\,, \qquad M_{12,s} = M_{12,s}^{\rm SM} \cdot \Delta_s\,; \qquad \Delta_s = |\Delta_s| e^{i\phi_s^\Delta} \tag{30}$$

With this parameterisation the physical mixing parameters can be written as

$$\Delta M_s = 2|M_{12,s}^{\rm SM}| \cdot |\Delta_s| \tag{31}$$

$$\Delta\Gamma_s = 2|\Gamma_{12,s}| \cdot \cos\left(\phi_s^{\rm SM} + \phi_s^\Delta\right) \tag{32}$$

$$\frac{\Delta\Gamma_s}{\Delta M_s} = \frac{|\Gamma_{12,s}|}{|M_{12,s}^{\rm SM}|} \cdot \frac{\cos\left(\phi_s^{\rm SM} + \phi_s^\Delta\right)}{|\Delta_s|} \tag{33}$$

$$a_{fs}^s = \frac{|\Gamma_{12,s}|}{|M_{12,s}^{\rm SM}|} \cdot \frac{\sin\left(\phi_s^{\rm SM} + \phi_s^\Delta\right)}{|\Delta_s|} \tag{34}$$

Now we combine the current experimental knowledge about the mixing parameters to find out whether B_s-mixing is described by the standard model alone, or whether

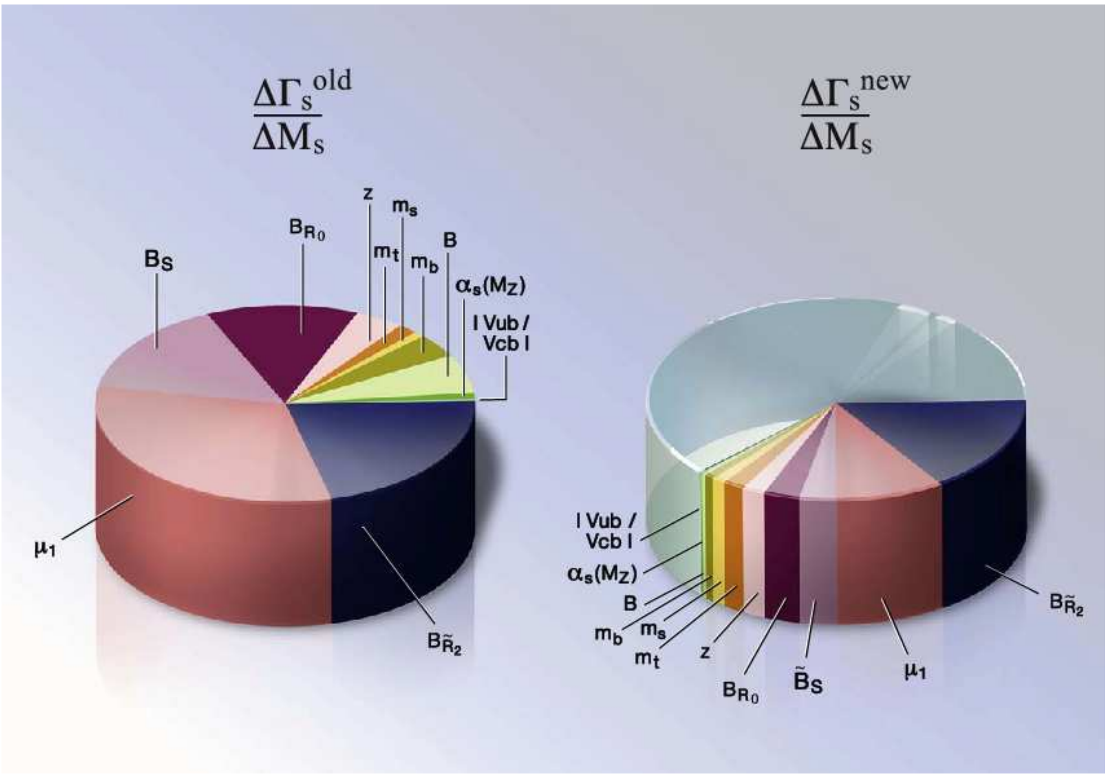

Figure 2: Error budget for the determination of $\Delta\Gamma_s/\Delta M_s$ in the old and the new basis.

we already get some signals of new physics contributions.
The mass difference ΔM_s is now known very precisely [26, 27]

$$\Delta M_s \;=\; 17.77 \pm 0.10_{(\mathrm{syst})} \pm 0.07_{\,(\mathrm{stat})}\,\mathrm{ps}^{-1} \qquad \mathrm{CDF}. \tag{35}$$

For the remaining mixing parameters in the B_s-system only experimental bounds are available. The width difference $\Delta\Gamma_s/\Gamma_s$ was investigated at ALEPH, BELLE, CDF, D0 by analyzing the decays $B_s \to D_s^{(*)+} + D_s^{(*)-}$ [37], $B_s \to J/\Psi + \phi$ [38] and $B_s \to K^+ + K^-$ [39] and the flavor specific lifetime of the B_s meson [40]. A recent combination of all these results yields [41]

$$\Delta\Gamma_s \;=\; 0.097 \pm 0.042\,\mathrm{ps}^{-1}\,, \tag{36}$$

$$\frac{\Delta\Gamma_s}{\Delta M_s} \;=\; (56 \pm 24) \times 10^{-4}\,. \tag{37}$$

Except the angular analysis $B_s \to J/\Psi + \phi$ all other determinations are affected by some drawbacks, described in [7]. Moreover the D0 collaboration has updated their results [38] for the decay $B_s \to J/\Psi + \phi$ in [17, 26, 42] using 1fb$^-$1 of data. Setting the value of the mixing phase ϕ_s to zero they obtain [17, 26, 42]

$$\Delta\Gamma_s = 0.12 \pm 0.08^{+0.03}_{-0.04}\,\mathrm{ps}^{-1}\,, \tag{38}$$

allowing for a non-zero value of the mixing phase ϕ_s they get

$$\begin{aligned} \Delta\Gamma_s &= 0.17 \pm 0.09 \pm 0.03\,\mathrm{ps}^{-1}\,, && (39)\\ \phi_s &= -0.79 \pm 0.56 \pm 0.01\,. && (40) \end{aligned}$$

In the following we will for $\Delta\Gamma_s$ and ϕ_s only use the numbers from Eq. (39) and Eq. (40).

The semileptonic CP asymmetry in the B_s system has been determined directly in [43] and found to be

$$a_{sl}^{s,\mathrm{direct}} = (24.5 \pm 19.3 \pm 3.5) \cdot 10^{-3}\,. \tag{41}$$

Moreover the semileptonic CP asymmetry can be extracted from the same sign dimuon asymmetry that was measured in [44] to be

$$a_{sl} = (-2.8 \pm 1.3 \pm 0.9) \cdot 10^{-3}\,. \tag{42}$$

Updating the numbers in [45, 46] one sees that

$$a_{sl} = (0.582 \pm 0.030)\ a_{sl}^d + (0.418 \pm 0.047)\ a_{sl}^s \tag{43}$$

In [45,46] the experimental bound for a_{sl}^d was used to extract from Eq.(42) and Eq.(43) a bound on a_{sl}^s. Due to the huge experimental uncertainties in a_{sl}^d this strategy resulted in a large error on a_{sl}^s. Since in the B_d-system there is not much room left for new physics contributions, we think it is justified to use the theoretical number of a_{sl}^d. Using $a_{sl}^d = -(0.48 \pm 0.12) \cdot 10^{-3}$ we get from Eq.(42), Eq.(43) and Eq.(42) already a nice bound

$$a_{sl}^{s,\mathrm{dimuon}} = (-6.0 \pm 3.2 \pm 2.2) \cdot 10^{-3}\,. \tag{44}$$

Combining this number with the direct determination [43] we get our final experimental number for the semileptonic CP asymmetries

$$a_{sl}^s = (-5.2 \pm 3.2 \pm 2.2) \cdot 10^{-3}\,. \tag{45}$$

Now we combine these experimental numbers with the theoretical errors to extract bounds in the imaginary Δ_s-plane by the use of Eqs. (31), (32), (33) and (34), see Fig. (3).

The comparison of experiment and standard model expectation for ΔM_s, $\Delta\Gamma_s$, ϕ_s, $\Delta\Gamma_s/\Delta M_s$ and a_{sl}^s presented in figure 3 already shows some hints for deviations from the standard model.

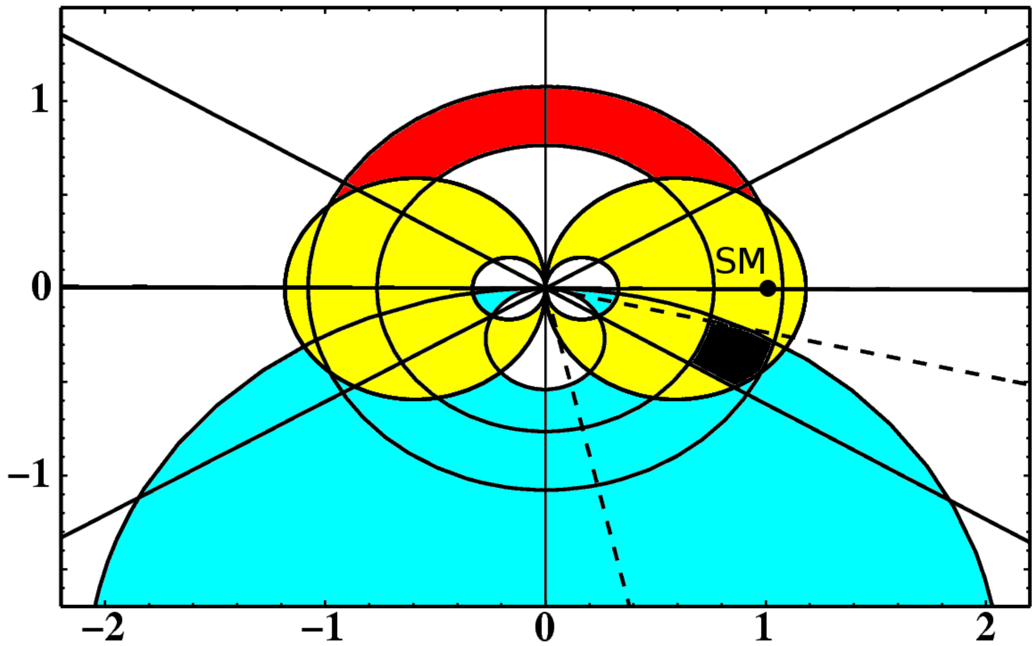

Figure 3: Current experimental bounds in the complex Δ_s-plane. The bound from ΔM_s is given by the red (dark-grey) ring around the origin. The bound from $\Delta\Gamma_s/\Delta M_s$ is given by the yellow (light-grey) region and the bound from a^s_{fs} is given by the light-blue (grey) region. The angle ϕ^Δ_s can be extracted from $\Delta\Gamma_s$ (solid lines) with a four fold ambiguity - one bound coincides with the x-axis! - or from the angular analysis in $B_s \to J/\Psi\phi$ (dashed line). If the standard model is valid all bounds should coincide in the point (1,0). The current experimental situation shows a small deviation, which might become significant, if the experimental uncertainties in $\Delta\Gamma_s$, a^s_{sl} and ϕ_s will go down in near future.

5 Conclusion and outlook

Theoretical predictions of the lifetimes of heavy mesons are in excellent agreement with the experimental numbers. We do not see any signal of possible duality violations. To become more quantitative in the prediction of τ_{B^+}/τ_{B_d} the non-perturbative estimates of the bag parameters B_1, B_2 and ϵ_1, ϵ_2 have to be improved. For τ_{B_s}/τ_{B_d} more precise experimental numbers are needed, while in the case of τ_{B_c} theoretical progress is mandatory.
The theoretical uncertainty in the mixing parameter ΔM is completely dominated by the decay constant. We have presented a method (see [7] for more details) to reduce the theoretical error in $\Delta\Gamma$, $\Delta\Gamma/\Delta M$ and a_{fs} considerably. This relatively clean standard model predictions can be used to look for new physics effects in B_s-mixing. From the currently available experimental bounds on $\Delta\Gamma_s$ and a_{fs} one already gets some hints for deviations from the standard model. This situation will improve dramatically as soon as more data are available.

For a further reduction of the theoretical uncertainty in $\Delta\Gamma$ a much higher accuracy than currently available on the decay constants is necessary. If this problem is solved or if one looks at quantities like $\Delta\Gamma/\Delta M$ and a_{fs} where the dependence on f_B cancels, then the dominant uncertainty comes from the unknown matrix elements of the power suppressed operators. Here any non-perturbative estimate would be very desirable. If accurate non-perturbative parameters are available one might think about NNLO calculations (α_s^2 or α_s/m_b-corrections) to reduce the remaining μ-dependence.

I would like to thank the organizers of HQL2006 for the invitation and Uli Nierste for the pleasant collaboration.

Bibliography

[1] A. Lenz, U. Nierste and G. Ostermaier, Phys. Rev. D **56** (1997) 7228 [arXiv:hep-ph/9706501]; A. Lenz, U. Nierste and G. Ostermaier, Phys. Rev. D **59** (1999) 034008 [arXiv:hep-ph/9802202]; A. Lenz, arXiv:hep-ph/0011258; O. Buchmüller, these proceedings; T. Mannel, these proceedings.

[2] M. Battaglia *et al.*, arXiv:hep-ph/0304132.

[3] M. A. Shifman and M. B. Voloshin, in: *Heavy Quarks* ed. V. A. Khoze and M. A. Shifman, Sov. Phys. Usp. **26** (1983) 387; M. A. Shifman and M. B. Voloshin, Sov. J. Nucl. Phys. **41** (1985) 120 [Yad. Fiz. **41** (1985) 187]; M. A. Shifman and M. B. Voloshin, Sov. Phys. JETP **64** (1986) 698 [Zh. Eksp. Teor. Fiz. **91** (1986) 1180];

[4] J. Chay, H. Georgi and B. Grinstein, Phys. Lett. B **247** (1990) 399; I. I. Bigi, N. G. Uraltsev and A. I. Vainshtein, Phys. Lett. B **293** (1992) 430 [Erratum-ibid. B **297** (1992) 477]; I. I. Y. Bigi, M. A. Shifman, N. G. Uraltsev and A. I. Vainshtein, Phys. Rev. Lett. **71** (1993) 496 [arXiv:hep-ph/9304225]; B. Blok, L. Koyrakh, M. A. Shifman and A. I. Vainshtein, "Differential distributions in semileptonic decays of the heavy flavors in Phys. Rev. D **49** (1994) 3356 [Erratum-ibid. D **50** (1994) 3572] [arXiv:hep-ph/9307247]; A. V. Manohar and M. B. Wise, Phys. Rev. D **49** (1994) 1310 [arXiv:hep-ph/9308246].

[5] B. Guberina, S. Nussinov, R. D. Peccei and R. Ruckl, Phys. Lett. B **89** (1979) 111; N. Bilic, B. Guberina and J. Trampetic, Nucl. Phys. B **248** (1984) 261; B. Guberina, R. Ruckl and J. Trampetic, Z. Phys. C **33** (1986) 297.

[6] V. Lubicz, these proceedings.

[7] A. Lenz and U. Nierste, arXiv:hep-ph/0612167.

[8] T. Onogi, arXiv:hep-lat/0610115.

[9] A. Lenz, arXiv:hep-ph/9906317; M. Beneke and A. Lenz, J. Phys. G **27** (2001) 1219 [arXiv:hep-ph/0012222]; A. Lenz and S. Willocq, J. Phys. G **27** (2001) 1207; A. Lenz, arXiv:hep-ph/0107033; A. Lenz, arXiv:hep-ph/0412007.

[10] I. I. Y. Bigi, B. Blok, M. A. Shifman, N. Uraltsev and A. I. Vainshtein, arXiv:hep-ph/9401298; I. I. Y. Bigi, arXiv:hep-ph/9508408; M. Neubert and C. T. Sachrajda, Nucl. Phys. B **483** (1997) 339 [arXiv:hep-ph/9603202].

[11] M. Beneke, G. Buchalla, C. Greub, A. Lenz and U. Nierste, Nucl. Phys. B **639** (2002) 389 [arXiv:hep-ph/0202106].

[12] E. Franco, V. Lubicz, F. Mescia and C. Tarantino, Nucl. Phys. B **633** (2002) 212 [arXiv:hep-ph/0203089].

[13] A. Lenz and U. Nierste, unpublished, e.g. talk at Academia Sinica 2003; F. Gabbiani, A. I. Onishchenko and A. A. Petrov, Phys. Rev. D **70** (2004) 094031 [arXiv:hep-ph/0407004].

[14] M. Di Pierro and C. T. Sachrajda [UKQCD Collaboration], Nucl. Phys. B **534** (1998) 373 [arXiv:hep-lat/9805028]; D. Becirevic, arXiv:hep-ph/0110124.

[15] A. Gray *et al.* [HPQCD Collaboration], Phys. Rev. Lett. **95** (2005) 212001 [arXiv:hep-lat/0507015].

[16] W. M. Yao *et al.* [Particle Data Group], J. Phys. G **33** (2006) 1.

[17] A. Cano, these proceedings.

[18] Y. Y. Keum and U. Nierste, Phys. Rev. D **57** (1998) 4282 [arXiv:hep-ph/9710512].

[19] M. Beneke, G. Buchalla and I. Dunietz, Phys. Rev. D **54** (1996) 4419 [arXiv:hep-ph/9605259].

[20] http://www.slac.stanford.edu/xorg/hfag/index.html

[21] C. H. Chang, S. L. Chen, T. F. Feng and X. Q. Li, Phys. Rev. D **64** (2001) 014003 [arXiv:hep-ph/0007162]; V. V. Kiselev, A. E. Kovalsky and A. K. Likhoded, Nucl. Phys. B **585** (2000) 353 [arXiv:hep-ph/0002127]. A. Y. Anisimov, I. M. Narodetsky, C. Semay and B. Silvestre-Brac, Phys. Lett. B **452** (1999) 129 [arXiv:hep-ph/9812514]. M. Beneke and G. Buchalla, Phys. Rev. D **53** (1996) 4991 [arXiv:hep-ph/9601249].

[22] A. Abulencia *et al.* [CDF Collaboration], Phys. Rev. Lett. **97** (2006) 012002 [arXiv:hep-ex/0603027]. D0 Collaboration, D0 conference note 4539

[23] T. Inami and C. S. Lim, Prog. Theor. Phys. **65** (1981) 297 [Erratum-ibid. **65** (1981) 1772].

[24] A. J. Buras, M. Jamin and P. H. Weisz, Nucl. Phys. B **347** (1990) 491.

[25] S. Aoki *et al.* [JLQCD Collaboration], Phys. Rev. Lett. **91** (2003) 212001 [arXiv:hep-ph/0307039].

[26] S. Menzemer, these proceedings.

[27] A. Abulencia *et al.* [CDF Collaboration], arXiv:hep-ex/0609040; A. Abulencia [CDF - Run II Collaboration], Phys. Rev. Lett. **97** (2006) 062003 [arXiv:hep-ex/0606027]; V. M. Abazov *et al.* [D0 Collaboration], Phys. Rev. Lett. **97** (2006) 021802 [arXiv:hep-ex/0603029].

[28] J.S. Hagelin, Nucl. Phys. **B193**, 123 (1981); E. Franco, M. Lusignoli and A. Pugliese, Nucl. Phys. **B194**, 403 (1982); L.L. Chau, Phys. Rep. **95**, 1 (1983); A.J. Buras, W. Słominski and H. Steger, Nucl. Phys. **B245**, 369 (1984); M.B. Voloshin, N.G. Uraltsev, V.A. Khoze and M.A. Shifman, Sov. J. Nucl. Phys. **46**, 112 (1987); A. Datta, E.A. Paschos and U. Türke, Phys. Lett. **B196**, 382 (1987); A. Datta, E.A. Paschos and Y.L. Wu, Nucl. Phys. **B311**, 35 (1988).

[29] M. Beneke, G. Buchalla, C. Greub, A. Lenz and U. Nierste, Phys. Lett. B **459** (1999) 631 [arXiv:hep-ph/9808385].

[30] M. Beneke, G. Buchalla, A. Lenz and U. Nierste, Phys. Lett. B **576** (2003) 173 [arXiv:hep-ph/0307344].

[31] M. Ciuchini, E. Franco, V. Lubicz, F. Mescia and C. Tarantino, JHEP **0308** (2003) 031 [arXiv:hep-ph/0308029].

[32] A. S. Dighe, T. Hurth, C. S. Kim and T. Yoshikawa, Nucl. Phys. B **624** (2002) 377 [arXiv:hep-ph/0109088].

[33] A. Lenz and U. Nierste, to appear.

[34] W. A. Bardeen, A. J. Buras, D. W. Duke and T. Muta, Phys. Rev. D **18** (1978) 3998.

[35] D. Becirevic, V. Gimenez, G. Martinelli, M. Papinutto and J. Reyes, JHEP **0204** (2002) 025 [arXiv:hep-lat/0110091].

[36] A. Weiler, these proceedings; T. Iijima, these proceedings; C. Tarantino, these proceedings; R. Fleischer, these proceedings.

[37] R. Barate *et al.* [ALEPH Collaboration], Phys. Lett. B **486** (2000) 286; CDF collaboration, conference note 7925, http://www-cdf.fnal.gov; D0 collaboration, conference note 5068, http://www-do.fnal.gov/; K. Ikado [Belle Collaboration], eConf **C060409** (2006) 003 [arXiv:hep-ex/0605068]; A. Drutskoy, arXiv:hep-ex/0605110; M. Paulini, these proceedings.

[38] D. Acosta *et al.* [CDF Collaboration], Phys. Rev. Lett. **94** (2005) 101803 [arXiv:hep-ex/0412057]; D0 collaboration, conference note 5052, http://www-do.fnal.gov/.

[39] D. Tonelli [CDF Collaboration], eConf **C060409** (2006) 001 [arXiv:hep-ex/0605038];

A. Abulencia [CDF Collaboration], arXiv:hep-ex/0607021.

[40] [Heavy Flavor Averaging Group (HFAG)], arXiv:hep-ex/0603003; V. M. Abazov *et al.* [D0 Collaboration], arXiv:hep-ex/0604046.

[41] R. Van Kooten, eConf **C060409** (2006) 031 [arXiv:hep-ex/0606005].

[42] D0 collaboration, conference note 5144, http://www-do.fnal.gov/.

[43] D0 collaboration, conference note 5143, http://www-do.fnal.gov/.

[44] V. Abazov [D0 Collaboration], "Measurement of the CP-violation parameter of B0 mixing and decay with p arXiv:hep-ex/0609014.

[45] D0 collaboration, conference note 5189, http://www-do.fnal.gov/.

[46] Y. Grossman, Y. Nir and G. Raz, Phys. Rev. Lett. **97** (2006) 151801 [arXiv:hep-ph/0605028].