B-Factories Legacy Book

CKM sides: V_{td} and V_{ts}

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Overview

- Theory details (possibly covered elsewhere)
  - Mixing through $\Delta F=2$ box diagrams
  - Vtd, Vts from $\Delta F=1$loop diagrams

- Experimental details (possibly covered elsewhere)
  - Description of a generic mixing/CP analysis
  - Description of inclusive/exclusive B -> $X_{s,d}$ gamma

- Physics results
  - Babar, Belle: Δm_d ; Tevatron: Δm_s
    - Lattice QCD dependence extracting $V_{td,ts}$ from $\Delta m_{d,s}$
  - Babar, Belle: excl./incl. BFs B -> $X_{s,d}$ gamma
    - Theory dependence enters in Vtd/Vts ratio calculation
  - Consistency of mixing and radiative penguin results

- Future prospects

Mixing Theory Details (possibly covered elsewhere)

- Mixing formalism for $B_{d,s}$ from time-dependent Sch. Eq. is needed to connect theory ($\Delta m_{d,s}$, $V_{td,ts}$) to experiment (Δt, Δz)

$$i\frac{d}{dt}\begin{pmatrix} |B_s(t)\rangle \\ |\bar{B}_s(t)\rangle \end{pmatrix} = \left(M^s - \frac{i}{2}\Gamma^s\right)\begin{pmatrix} |B_s(t)\rangle \\ |\bar{B}_s(t)\rangle \end{pmatrix}$$

$$\Delta m_B = 2|M_{12}| = \frac{G_F^2}{6\pi^2}\eta_B m_B \boxed{\hat{B}_B f_B^2} M_W^2 S\left(\frac{m_t^2}{M_W^2}\right)|V_{tb}V_{td}^*|^2$$

Lattice QCD dependence

- Relevant discussion given in Babar Physics Book (Sec. 11.2) is probably too lengthy, but is a good example of the level of detail needed for a reasonably complete discussion that is accessible a grad student level

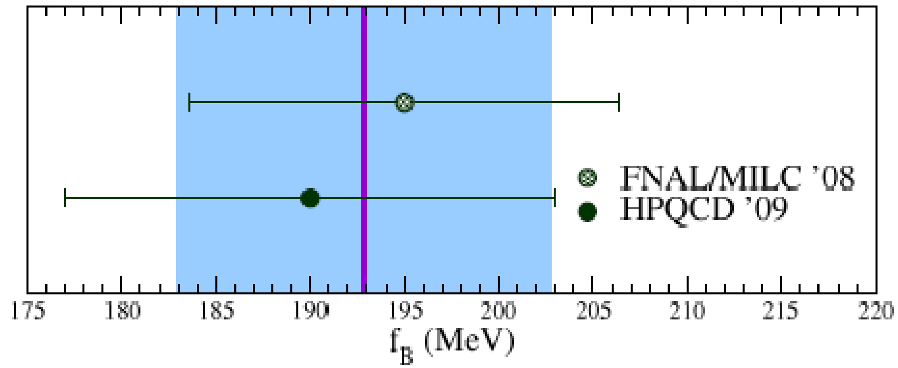
Lattice Inputs

Averages taken from Laiho, Van de Water, Lunghi, "Lattice QCD inputs to the CKM unitarity triangle analysis", PRD 81,034503 (2010)

	f_B(MeV)	$(\delta f_B)_{\rm stat}$	$(\delta f_B)_{\rm syst}$
FNAL/MILC '08 [28]	195	7	9
HPQCD '09 [29]	190	7	11
Average	192.8 ± 9.9		
	f_{B_s}(MeV)	$(\delta f_{B_s})_{\rm stat}$	$(\delta f_{B_s})_{\rm syst}$
FNAL/MILC '08 [28]	243	6	9
HPQCD '09 [29]	231	5	14
Average	238.8 ± 9.5		

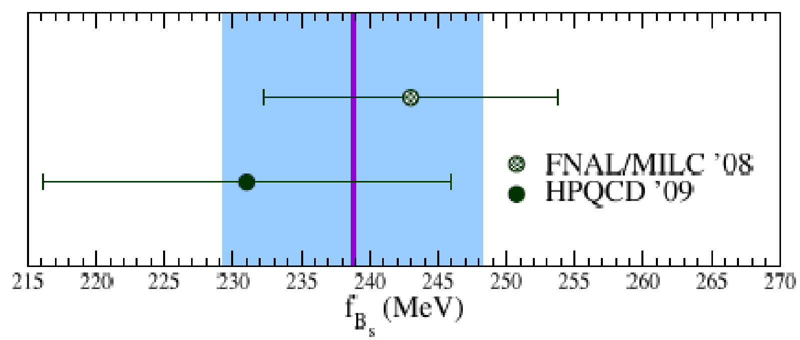
TABLE II: Unquenched lattice QCD determinations of the B-meson decay constants f_B and f_{B_s}.

Plots showing the $N_f = 2+1$ results and their averages are given in Figs. 6 and 7.



	$\widehat{B}_{B_d}$	$\widehat{B}_{B_s}$
HPQCD '09 [29]	1.26 ± 0.11	1.33 ± 0.06

TABLE III: Unquenched lattice QCD determinations of the neutral B-meson bag parameters $\widehat{B}_{B_q}$.



Lattice Inputs

	$f_B\sqrt{\widehat{B}_{B_d}}$(MeV)	$f_{B_s}\sqrt{\widehat{B}_{B_s}}$(MeV)
Average	216 ± 15	275 ± 13

TABLE IV: Unquenched lattice QCD averages of the neutral B-meson mixing matrix elements $f_B\sqrt{\widehat{B}_{B_d}}$ and $f_{B_s}\sqrt{\widehat{B}_{B_s}}$. The results are obtained by combining the average decay constants given in Table II with the HPQCD determinations of the bag-parameters presented in Table III, thereby minimizing the total uncertainties.

$$\xi \equiv f_{B_s}\sqrt{\widehat{B}_{B_s}}/f_{B_d}\sqrt{\widehat{B}_{B_d}}$$

	ξ	$(\delta\xi)_{\rm stat}$	$(\delta\xi)_{\rm syst}$
FNAL/MILC '08 [32]	1.205	0.036	0.037
HPQCD '09 [29]	1.258	0.025	0.021
Average	1.243 ± 0.028		

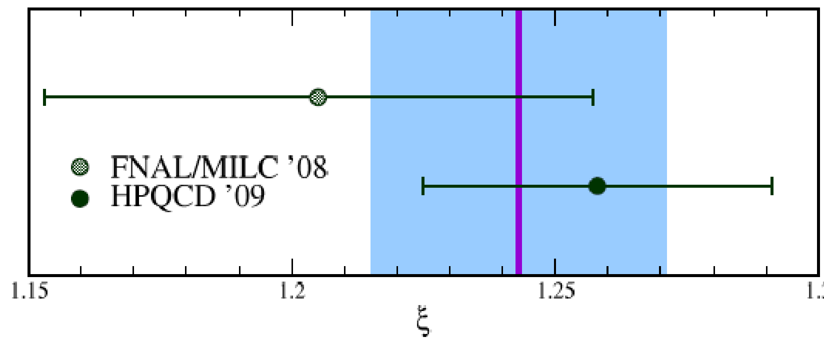


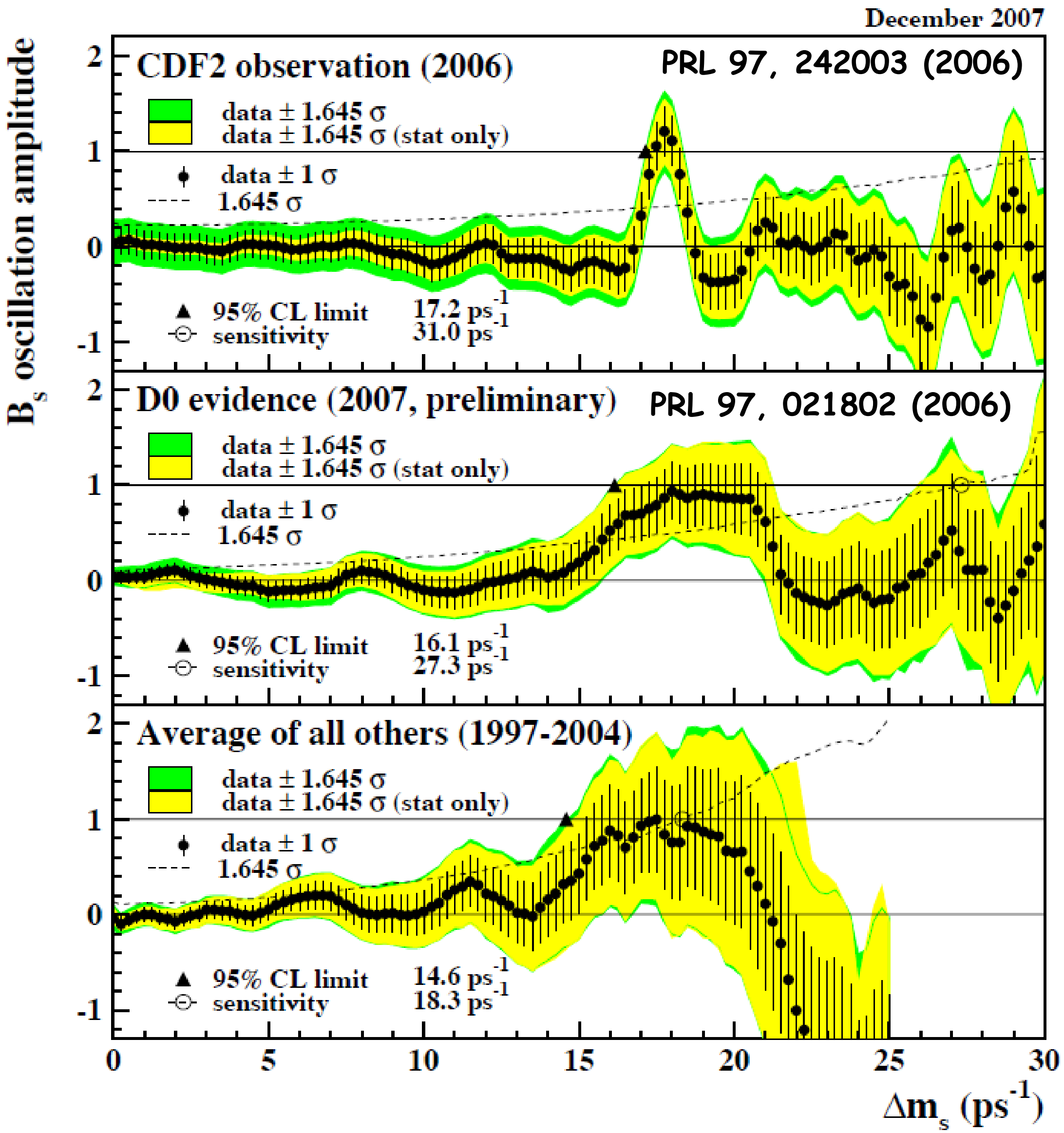
TABLE V: Unquenched lattice QCD determinations of the $SU(3)$-breaking ratio ξ. A plot showing the two $N_f = 2+1$ results and their average is given in Fig. 8.

Tagged Mixing/CP Analysis Experimental Details (possibly covered elsewhere)

- Description of a generic mixing/CP analysis description outlined at hep-ex/0201020 (PRD 66, 032003 [2002])

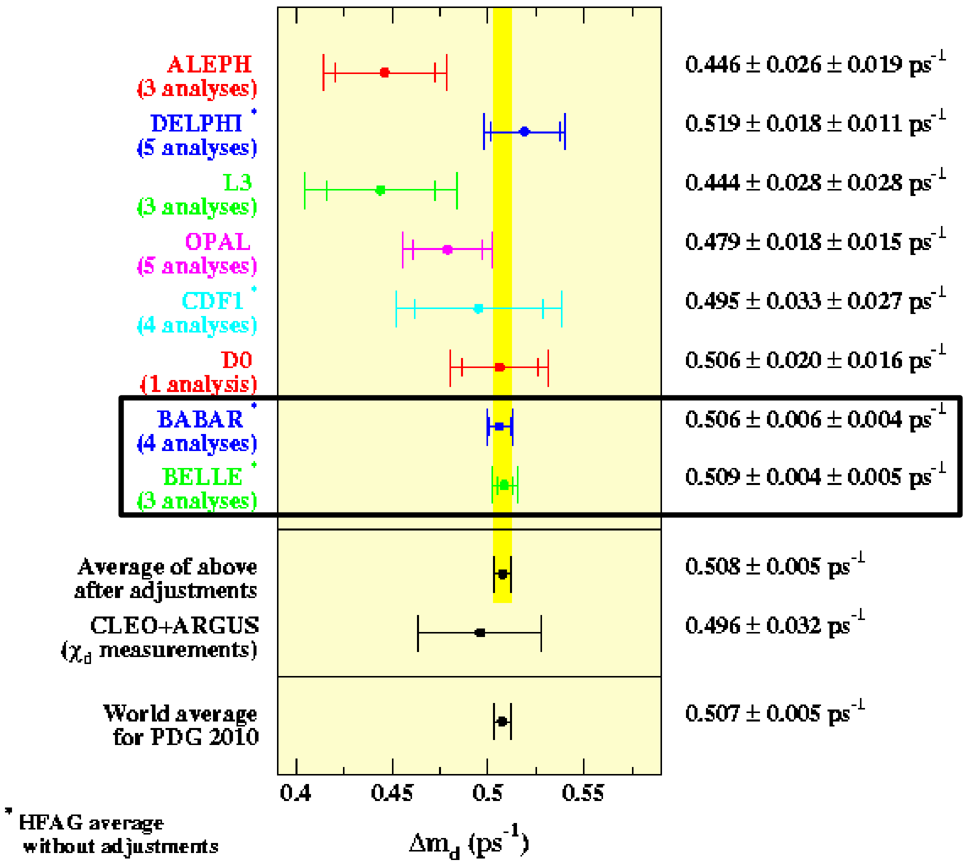
- Selection of the B_{CP} sample of signal events for neutral B decays to CP modes $J/\psi K^0_S$, $\psi(2S)K^0_S$, $\chi_{c1}K^0_S$, $J/\psi K^{*0}$ ($K^{*0} \to K^0_S\pi^0$), and $J/\psi K^0_L$; selection of the $B_{\rm flav}$ sample of signal events for neutral flavor-eigenstate decays to $D^{(*)-}\pi^+/\rho^+/a_1^+$ and $J/\psi K^{*0}$ ($K^{*0} \to K^+\pi^-$); selection of the B^+ control sample in the modes $\overline{D}^{(*)0}\pi^+$, $J/\psi K^{(*)+}$, $\psi(2S)K^+$, $\chi_{c1}K^+$; and selection of a semileptonic neutral B sample in the mode $D^{*+}\ell^-\overline{\nu}$, as described in Section III;
- Determination of the flavor of the $B_{\rm tag}$, as described in Section IV;
- Measurement of the distance Δz between the two B^0 decay vertices along the $\Upsilon(4S)$ boost axis, and its conversion to Δt, as described in Section V;
- Construction of a log-likelihood function to describe the time evolution of signal and background events in the presence of mixing and CP asymmetries, as described in Section VI;
- Measurement of the mixing rate Δm_d, mistag fractions w_i, and vertex resolution parameters $\hat{a}_i$ for the different tagging categories i, with an unbinned maximum-likelihood fit to the $B_{\rm flav}$ sample, as described in Section VII;
- Extraction of a value of sin2β, or more generally $Im\lambda/|\lambda|$ and $|\lambda|$, from the amplitude of the CP asymmetry, the mistag fractions w_i, and the vertex resolution parameters $\hat{a}_i$ for the different tagging categories i, with an unbinned maximum-likelihood fit to the combined $B_{\rm flav}$ and B_{CP} samples, as described in Section VIII.

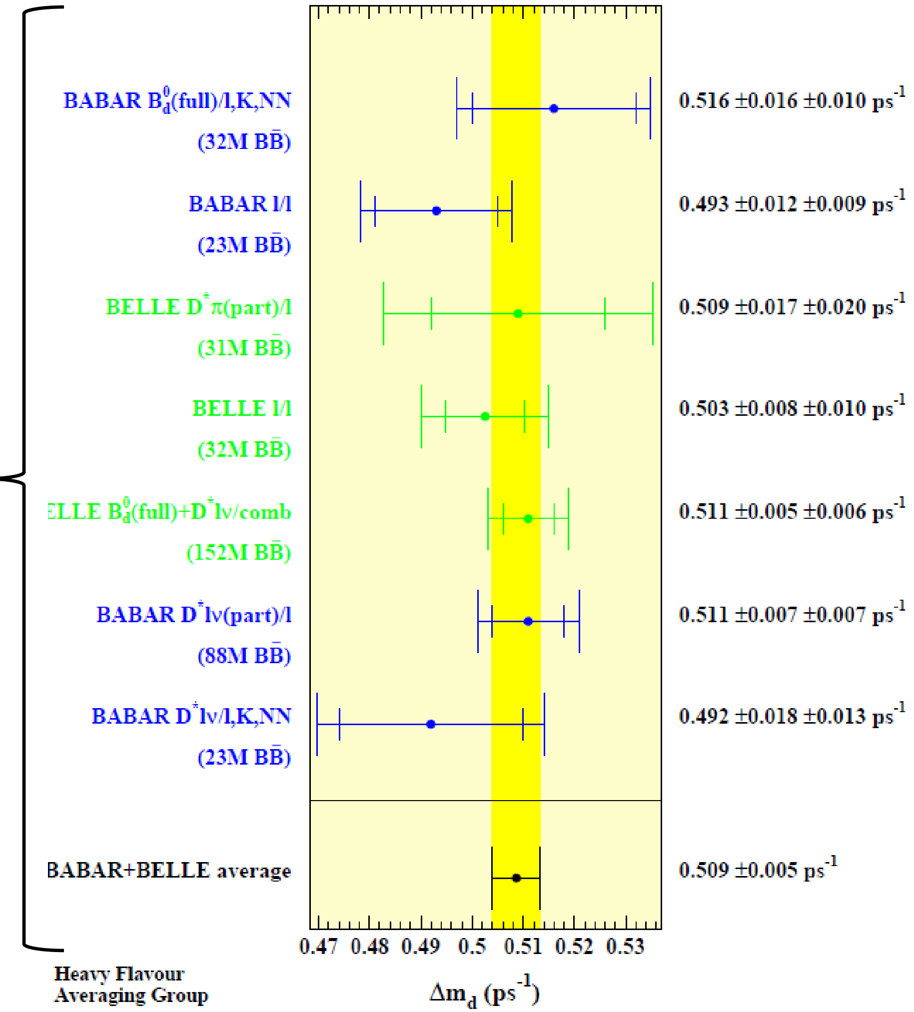
Δm_s Experimental Results (CDF/Tevatron)



$\Delta m_s = 17.77 \pm 0.10$ (stat) ± 0.07 (syst) ps^{-1}

Δm_d Experimental Results (HFAG 2010)





Δm_d B-Factory Experimental Results (HFAG 2010)

BELLE

Studies of B0 - anti-B0 mixing properties with inclusive dilepton events

[8] N.C. Hastings *et al.* (Belle Collaboration), Phys. Rev. D **67**, 052004 (2003).

Improved measurement of CP-violation parameters sin 2phi(1) and |lambda|, B meson lifetimes, and B0 - anti-B0 mixing parameter Delta m(d)

[72] K. Abe *et al.* (Belle Collaboration), Phys. Rev. D **71**, 072003 (2005).

Measurement of the B0 - anti-B0 mixing rate with B0 (anti-B0) ---> D*-+ pi+- partial reconstruction

[133] Y. Zheng *et al.* (Belle Collaboration), Phys. Rev. D **67**, 092004 (2003).

BABAR

Simultaneous measurement of the B0 meson lifetime and mixing frequency with B0 --> D*- l+ nu(l) decays

[69] B. Aubert *et al.* (Babar Collaboration), Phys. Rev. D **67**, 072002 (2003).

Measurement of the anti-B0 lifetime and the B0 anti-B0 oscillation frequency using partially reconstructed anti-B0 ---> D*+ l- anti-nu(l) decays

[71] B. Aubert *et al.* (Babar Collaboration), Phys. Rev. D **73**, 012004 (2006).

Measurement of B0 - anti-B0 flavor oscillations in hadronic B0 decays

[131] B. Aubert *et al.* (Babar Collaboration), Phys. Rev. Lett. **88**, 221802 (2002) and Phys. Rev. D **66**, 032003 (2002).

Measurement of the B0 - anti-B0 oscillation frequency with inclusive dilepton events

[132] B. Aubert *et al.* (Babar Collaboration), Phys. Rev. Lett. **88**, 221803 (2002).

Vtd/Vts from Radiative Penguins

- Exclusive decays:

  Babar: PRD 78, 112001 (2008) $|V_{td}/V_{ts}|_{\rho/\omega} = 0.233^{+0.025+0.022}_{-0.024-0.021}$

  Belle: PRL 101, 111801 (2008) $|V_{td}/V_{ts}| = 0.195\,^{+0.020}_{-0.019}(\text{exp.}) \pm 0.015(\text{th.})$

- Relatively large theory uncertainty in calculating ratio

$$\frac{\mathcal{B}[B \to \rho(\omega)\gamma]}{\mathcal{B}(B \to K^*\gamma)} = S\left|\frac{V_{td}}{V_{ts}}\right|^2 \cdot \left(\frac{1 - m^2_{\rho(\omega)}/m^2_B}{1 - m^2_{K^*}/m^2_B}\right)^3 \zeta^2_{\rho(\omega)}\left[1 + \Delta R_{\rho(\omega)}\right]. \tag{1}$$

The coefficient S is 1 for ρ^+ and $\frac{1}{2}$ for ρ^0 or ω, m is the particle mass, $\zeta_{\rho(\omega)}$ is the ratio of the form factors for the decays $B \to \rho(\omega)\gamma$ and $B \to K^*\gamma$, and $\Delta R_{\rho(\omega)}$ accounts for differences in decay dynamics, including weak annihi-

Vtd/Vts from Radiative Penguins

- Inclusive decays →

Babar Xdgamma result shown at conference, paper soon

- Small theory uncertainties in calculating ratio

$$|V_{td}/V_{ts}| = \qquad \pm 0.002(th.)$$

$$\frac{\Gamma(b \to d\gamma)}{\Gamma(b \to s\gamma)} = \zeta^2 \left|\frac{V_{td}}{V_{ts}}\right|^2 (1 + \Delta R)$$

where ζ accounts for any remaining SU(3) breaking and ΔR accounts for weak annihilation in B^+ decays

Future Prospects

- Somewhat better precision in lattice inputs needed for mixing-based ratio will likely appear over time

- Precision in ratio from exclusive final state radiative penguins already limited by theory inputs, and no substantial improvements seem likely

- Vtd/Vts from inclusive radiative penguins may achieve total uncertainty of just a few percent with ~10/ab Super-FF dataset

- In the long run, final ~50-100/ab Super-FF datasets will also allow ratio from B->Xll
  - With SM B->$X_d$ll rate should also be able to probe Vtd/Vts as a function of di-lepton mass

Some Final Details

- Belle co-editor still needed
  - Lacking this, at least Belle review of relevant material
- Expect to need 4-6 pages
- **Debbie Bard** has agreed to contribute Vtd/Vts discussion
  - Lead analyst for Babar semi-inclusive B->Xdgamma
- The selection of material here has been discussed in general terms with **Tobias Hurth** (theory ed.), but the details presented here still need to be reviewed and agreed upon
- Will be useful to see initial draft of Radiative Penguin and Mixing sections in order to guide the writing here