QCD Calculations for New-Physics Searches

Ulrich Nierste

Karlsruhe Institute of Technology

Federal Ministry
of Education
and Research

Colour meets Flavour
Siegen, October 2011

A. Lenz and UN: *Numerical updates of lifetimes and mixing parameters of B mesons*, 1102.4274, Proc. of *CKM 2010*.

Analytical input: NLO QCD calculations in

- Y. Y. Keum, UN, Phys. Rev. D **57** (1998) 4282,
- M. Beneke, G. Buchalla, C. Greub, A. Lenz, UN, Phys. Lett. B **459**, 631 (1999),
- M. Beneke, G. Buchalla, C. Greub, A. Lenz, UN, Nucl. Phys. B **639**, 389 (2002),
- M. Beneke, G. Buchalla, A. Lenz, UN, Phys. Lett. B **576** (2003) 173,
- A. Lenz, UN, JHEP **0706**, 072 (2007)

This talk: Numerical updates confronted with data of summer 2011.

B meson lifetimes

Calculational framework: Operator Product Expansion
(Heavy Quark Expansion)

$\Rightarrow$ simultaneous expansion of decay rate Γ in $\frac{\Lambda_{QCD}}{m_b}$ and α_s

see talk bei Alex Lenz.

The neutral mesons B_d and B_s mix with their antiparticles, the eigenstates $B_L^{d,s}$ and $B_H^{d,s}$ differ in their masses and widths:

$$
\begin{aligned}
M_H^q &= M_{B_q} + \frac{\Delta m_q}{2}, \qquad & \Gamma_H^q &= \Gamma_q - \frac{\Delta\Gamma_q}{2} \\
M_L^q &= M_{B_q} - \frac{\Delta m_q}{2}, \qquad & \Gamma_L^q &= \Gamma_q + \frac{\Delta\Gamma_q}{2}
\end{aligned}
$$

The average B_s width

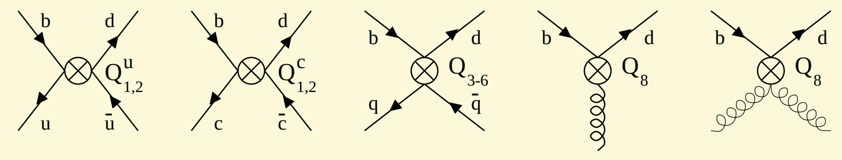
Define

$$\tau_{B_s} \equiv \frac{1}{\Gamma_s}.$$

Discuss

$$\frac{\tau_{B_s}}{\tau_{B_d}}.$$

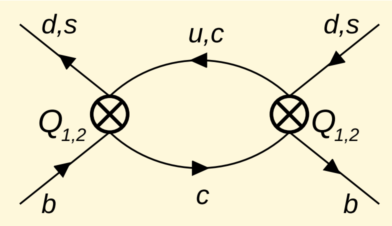
Operators:



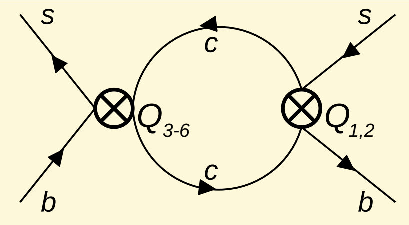
Wilson Coefficients $|C_{1,2}| \gg |C_{3,\ldots 8}|$.

Weak annihilation

contributes to τ_{B_d}, τ_{B_s}:

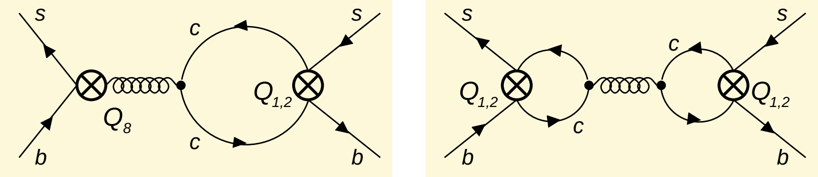


contributes only to τ_{B_s}:



The left diagram gives practically the same result for B_s and B_d.
The right diagram comes with small penguin coefficients $C_{3\ldots6}$.

More small diagrams contributing to τ_{B_s}:



The prediction of τ_{B_s}/τ_{B_d} involves four hadronic matrix element parametrised by $f_B^2 B_1$, $f_B^2 B_2$, $f_B^2 \epsilon_1$ and $f_B^2 \epsilon_2$.

Neubert,Sachrajda 1996

2011 update using $f_{B_s}/f_{B_d} = 1.209 \pm 0.007 \pm 0.023$:

$$\frac{\tau_{B_s}}{\tau_{B_d}} - 1 = \\ 10^{-3} \cdot \left(\frac{f_{B_s}}{231\ \mathrm{MeV}} \right)^2 \Big[(0.77 \pm 0.10) B_1 - (1.00 \pm 0.13) B_2 \\ + (36 \pm 5)\epsilon_1 - (51 \pm 7)\epsilon_2 \Big].$$

The prediction of τ_{B_s}/τ_{B_d} involves four hadronic matrix element parametrised by $f_B^2 B_1$, $f_B^2 B_2$, $f_B^2 \epsilon_1$ and $f_B^2 \epsilon_2$.

Neubert,Sachrajda 1996

2011 update using $f_{B_s}/f_{B_d} = 1.209 \pm 0.007 \pm 0.023$:

$$\frac{\tau_{B_s}}{\tau_{B_d}} - 1 =$$

$$10^{-3} \cdot \left(\frac{f_{B_s}}{231\text{ MeV}} \right)^2 \left[(0.77 \pm 0.10) B_1 - (1.00 \pm 0.13) B_2 + (36 \pm 5)\epsilon_1 - (51 \pm 7)\epsilon_2 \right].$$

With 2001 quenched lattice values for $B_{1,2}$ and $\epsilon_{1,2}$ (Bečirević hep-ph/0110124) find:

$$-4 \cdot 10^{-3} \le \frac{\tau_{B_s}}{\tau_{B_d}} - 1 \le 0$$

Update of Feb 2011:

$$-4 \cdot 10^{-3} \leq \frac{\tau_{B_s}}{\tau_{B_d}} - 1 \leq 0$$

Update of Feb 2011:

$$-4 \cdot 10^{-3} \leq \frac{\tau_{B_s}}{\tau_{B_d}} - 1 \leq 0$$

LHCb, Lepton-Photon 2011: τ_{B_s} measured in $B_s \to J/\psi\phi$:

$$\frac{\tau_{B_s}}{\tau_{B_d}} = 0.9996 \pm 0.0201$$

in excellent agreement with the SM preciction.

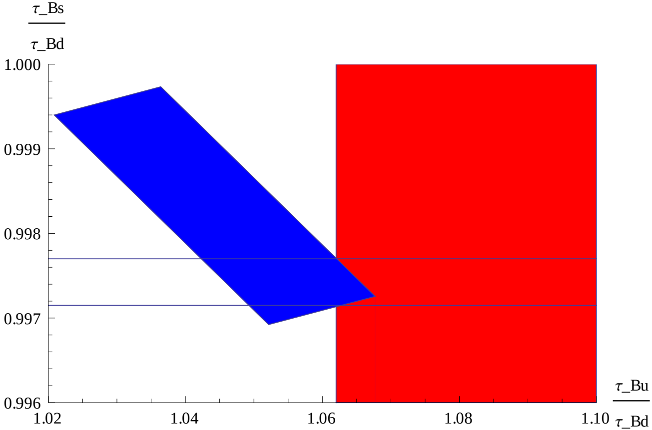
Next: Confront $\tau_{B^+}/\tau_{B_d} = 1.081 \pm 0.006$ with

$$\frac{\tau_{B^+}}{\tau_{B_d}} - 1 =$$

$$0.0324 \left(\frac{f_B}{200\,\mathrm{MeV}}\right)^2 \Big[(1.0 \pm 0.2)\, B_1 \; + \; (0.1 \pm 0.1)\, B_2$$

$$- \; (17.8 \pm 0.9)\, \epsilon_1 \; + \; (3.9 \pm 0.2)\, \epsilon_2 - 0.26 \Big]$$

Correlate τ_{B_s}/τ_{B_d} with τ_{B^+}/τ_{B_d}:



Blue: Theory prediction with 2001 lattice data

Red: Experimental 3σ region for τ_{B^+}/τ_{B_d}.

$\mathrm{B}-\overline{\mathrm{B}}$ mixing in the Standard Model

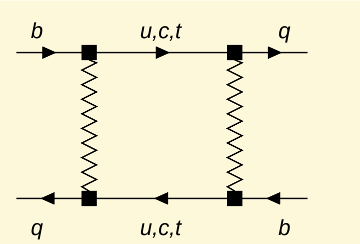
$\mathrm{B_q}-\overline{\mathrm{B}}_{\mathrm{q}}$ mixing with $q = d$ or $q = s$ involves the 2×2 matrices M and Γ.

$\mathrm{B}-\overline{\mathrm{B}}$ mixing in the Standard Model

$\mathrm{B_q}-\overline{\mathrm{B}}_\mathrm{q}$ mixing with $q = d$ or $q = s$ involves the 2×2 matrices M and Γ.

The mass matrix element M_{12}^{q} stems from the dispersive (real) part of the box diagram, internal t.

The decay matrix element Γ_{12}^{q} stems from the absorpive (imaginary) part of the box diagram, internal c, u.

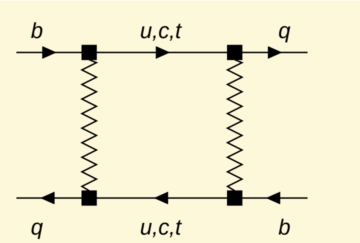


$\mathrm{B}-\overline{\mathrm{B}}$ mixing in the Standard Model

$\mathrm{B_q}-\overline{\mathrm{B}}_\mathrm{q}$ mixing with $q=d$ or $q=s$ involves the 2×2 matrices M and Γ.

The mass matrix element M_{12}^{q} stems from the dispersive (real) part of the box diagram, internal t.

The decay matrix element Γ_{12}^{q} stems from the absorpive (imaginary) part of the box diagram, internal c, u.



3 physical quantities in $\mathrm{B_q}-\overline{\mathrm{B}}_\mathrm{q}$ mixing:

$$\left|M_{12}^{q}\right|, \quad \left|\Gamma_{12}^{q}\right|, \quad \phi_q \equiv \arg\left(-\frac{M_{12}^{q}}{\Gamma_{12}^{q}}\right)$$

The two eigenstates found by diagonalising $M - i\,\Gamma/2$ differ in their masses and widths:

$$\begin{array}{lrcl} \text{mass difference} & \Delta m_q & \simeq & 2|M_{12}^q|, \\ \text{width difference} & \Delta\Gamma_q & \simeq & 2|\Gamma_{12}^q|\cos\phi_q \end{array}$$

The two eigenstates found by diagonalising $M - i\,\Gamma/2$ differ in their masses and widths:

$$\begin{array}{lrcl} \text{mass difference} & \Delta m_q & \simeq & 2|M_{12}^q|, \\ \text{width difference} & \Delta\Gamma_q & \simeq & 2|\Gamma_{12}^q|\cos\phi_q \end{array}$$

CP asymmetry in flavor-specific decays (semileptonic CP asymmetry):

$$a_{\mathrm{fs}}^q = \frac{|\Gamma_{12}^q|}{|M_{12}^q|}\sin\phi_q$$

Generic new physics

Phases $\phi_q = \arg(-M_{12}^q/\Gamma_{12}^q)$ in the Standard Model:

$$\phi_d^{\rm SM} = -4.3^\circ \pm 1.4^\circ, \qquad \phi_s^{\rm SM} = 0.2^\circ.$$

Define the complex parameters Δ_d and Δ_s through

$$M_{12}^q \equiv M_{12}^{\rm SM,q} \cdot \Delta_q \,, \qquad \Delta_q \equiv |\Delta_q| e^{i\phi_q^\Delta} .$$

In the Standard Model $\Delta_q = 1$. Use $\phi_s = \phi_s^{\rm SM} + \phi_s^\Delta \simeq \phi_s^\Delta$.

Generic new physics

Phases $\phi_q = \arg(-M_{12}^q/\Gamma_{12}^q)$ in the Standard Model:

$$\phi_d^{\mathrm{SM}} = -4.3^\circ \pm 1.4^\circ, \qquad \phi_s^{\mathrm{SM}} = 0.2^\circ.$$

Define the complex parameters Δ_d and Δ_s through

$$M_{12}^q \equiv M_{12}^{\mathrm{SM,q}} \cdot \Delta_q\,, \qquad \Delta_q \equiv |\Delta_q| e^{i\phi_q^\Delta}.$$

In the Standard Model $\Delta_q = 1$. Use $\phi_s = \phi_s^{\mathrm{SM}} + \phi_s^\Delta \simeq \phi_s^\Delta$.
The measurements

$$\begin{aligned} \Delta m_s &= (17.77 \pm 0.10 \pm 0.07)\ \mathrm{ps}^{-1} && \text{CDF} \\ \Delta m_s &= (17.63 \pm 0.11 \pm 0.04)\ \mathrm{ps}^{-1} && \text{LHCb (prelim)} \end{aligned}$$

imply

$$|\Delta_s| = 1.03 \pm 0.14_{(\mathrm{th})} \pm 0.01_{(\mathrm{exp})}$$

Summer 2010

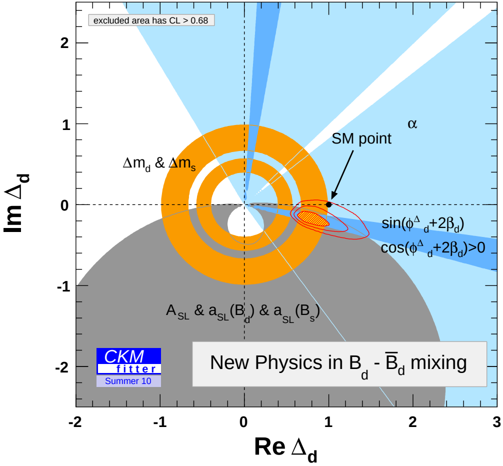
Global analysis of $\mathrm{B_s}-\overline{\mathrm{B}}_\mathrm{s}$ mixing and $\mathrm{B_d}-\overline{\mathrm{B}}_\mathrm{d}$ mixing with
A. Lenz and the CKMfitter Group (J. Charles,
S. Descotes-Genon, A. Jantsch, C. Kaufhold, H. Lacker,
S. Monteil, V. Niess) arXiv:1008.1593

Rfit method: No statistical meaning is assigned to systematic errors and theoretical uncertainties.

We have performed a simultaneous fit to the Wolfenstein parameters and to the new physics parameters Δ_s and Δ_d:

$$\Delta_q \equiv \frac{M_{12}^q}{M_{12}^{q,\mathrm{SM}}}, \qquad \Delta_q \equiv |\Delta_q| e^{i\phi_q^\Delta}.$$

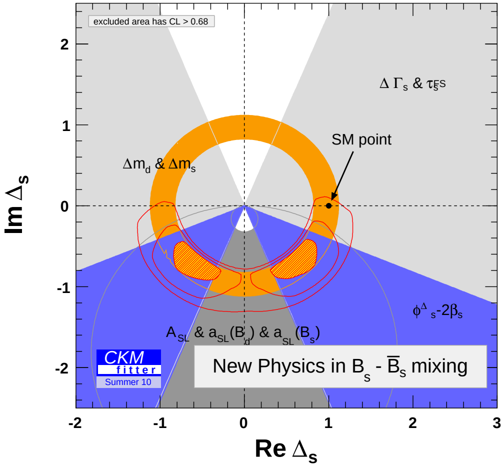
Result for $B_d-\overline{B}_d$ mixing:



SM point $\Delta_d = 1$ disfavored by 2.7σ.

Main driver: $B^+ \to \tau^+\nu_\tau$

Result for $B_s-\overline{B}_s$ mixing:



SM point $\Delta_s = 1$ disfavored by 2.7σ.

with 2010 combination of 2009 CDF/DØ data on $B_s \to J/\psi\phi$ and 2010 DØ dimuon CP asymmetry

Summer 2010 p-values:

Hypothesis	p-value
$\Delta_d = 1$ (2D)	2.7 σ
$\Delta_s = 1$ (2D)	2.7 σ
$\Delta_d = \Delta_s$ (2D)	2.1 σ
$\Delta_d = \Delta_s = 1$ (4D)	3.6 σ

Summer 2011

The mixing-induced CP asymmetries in $B_s \to J/\psi\phi$ and $B_s \to J/\psi f_0$ determine $\phi_s^\Delta - 2\beta_s$ with $2\beta_s = 2.2^\circ$.

CDF 2010, $J/\psi\phi$: $\phi_s^\Delta = -23^\circ{}^{+23^\circ}_{-34^\circ}$

DØ EPS 2011, $J/\psi\phi$: $\phi_s^\Delta = -30^\circ{}^{+22^\circ}_{-21^\circ}$

LHCb LP 2011, $J/\psi f_0$: $\phi_s^\Delta = -23^\circ \pm 25^\circ \pm 1^\circ$

LHCb LP 2011, $J/\psi\phi$: $\phi_s^\Delta = 9.6^\circ \pm 10.3^\circ \pm 4.0^\circ$

all at $68\%\mathrm{CL}$

Summer 2011

The mixing-induced CP asymmetries in $B_s \to J/\psi\phi$ and $B_s \to J/\psi f_0$ determine $\phi_s^\Delta - 2\beta_s$ with $2\beta_s = 2.2^\circ$.

CDF 2010, $J/\psi\phi$: $\phi_s^\Delta = -23^\circ{}^{+23^\circ}_{-34^\circ}$

DØ EPS 2011, $J/\psi\phi$: $\phi_s^\Delta = -30^\circ{}^{+22^\circ}_{-21^\circ}$

LHCb LP 2011, $J/\psi f_0$: $\phi_s^\Delta = -23^\circ \pm 25^\circ \pm 1^\circ$

LHCb LP 2011, $J/\psi\phi$: $\phi_s^\Delta = 9.6^\circ \pm 10.3^\circ \pm 4.0^\circ$

all at $68\%\mathrm{CL}$

LHCb LP 2011 average: $\phi_s^\Delta = 3.9^\circ \pm 9.2^\circ \pm 4.0^\circ$

Summer 2011

The mixing-induced CP asymmetries in $B_s \to J/\psi\phi$ and $B_s \to J/\psi f_0$ determine $\phi_s^\Delta - 2\beta_s$ with $2\beta_s = 2.2^\circ$.

CDF 2010, $J/\psi\phi$: $\phi_s^\Delta = -23^{\circ}{}^{+23^\circ}_{-34^\circ}$

DØ EPS 2011, $J/\psi\phi$: $\phi_s^\Delta = -30^{\circ}{}^{+22^\circ}_{-21^\circ}$

LHCb LP 2011, $J/\psi f_0$: $\phi_s^\Delta = -23^\circ \pm 25^\circ \pm 1^\circ$

LHCb LP 2011, $J/\psi\phi$: $\phi_s^\Delta = 9.6^\circ \pm 10.3^\circ \pm 4.0^\circ$

all at $68\%\mathrm{CL}$

LHCb LP 2011 average: $\phi_s^\Delta = 3.9^\circ \pm 9.2^\circ \pm 4.0^\circ$

My average: $\phi_s^\Delta = -1.8^\circ \pm 8.6^\circ$

with CDF/DØ errors inflated by a factor of 1.25 as a guesstimate for correlations.

All measurements are in mutual agreement and consistent with the SM prediction $\phi_s^\Delta = 0$.

But:

30 Jun 2011: DØ result presents the semileptonic CP asymmetry measured in the dimuon channel:

$$a_{\mathrm{fs}} = (-7.87 \pm 1.72 \pm 0.93) \cdot 10^{-3}$$

for a mixture of B_d and B_s mesons with

$$a_{\mathrm{fs}} \quad = \quad (0.594 \pm 0.022) a_{\mathrm{fs}}^d + (0.406 \pm 0.022) a_{\mathrm{fs}}^s$$

The result is 3.9σ away from $a_{\mathrm{fs}}^{\mathrm{SM}} = (-0.24 \pm 0.03) \cdot 10^{-3}$.

A. Lenz, UN 2011

But:

30 Jun 2011: DØ result presents the semileptonic CP asymmetry measured in the dimuon channel:

$$a_{\rm fs} = (-7.87 \pm 1.72 \pm 0.93) \cdot 10^{-3}$$

for a mixture of B_d and B_s mesons with

$$a_{\rm fs} \quad = \quad (0.594 \pm 0.022) a_{\rm fs}^d + (0.406 \pm 0.022) a_{\rm fs}^s$$

The result is 3.9σ away from $a_{\rm fs}^{\rm SM} = (-0.24 \pm 0.03) \cdot 10^{-3}$.

A. Lenz, UN 2011

$a_{\rm fs}$ favours $\phi_s^\Delta < 0$ in agreement with the $A_{\rm CP}^{\rm mix}(B_s \to J/\psi\phi)$ measurements of CDF and DØ and $A_{\rm CP}^{\rm mix}(B_s \to J/\psi f_0)$ from LHCb.... but no agreement with $A_{\rm CP}^{\rm mix}(B_s \to J/\psi\phi)$ from LHCb.

Theory prediction with new physics:

$$a_{\mathrm{fs}} = (3.2 \pm 0.6) \cdot 10^{-3} \frac{\sin \phi_d^\Delta}{|\Delta_d|} + (2.1 \pm 0.4) \cdot 10^{-3} \frac{\sin \phi_s^\Delta}{|\Delta_s|}$$

A. Lenz, UN 2011

$\Rightarrow$ The central value of

$$a_{\mathrm{fs}} = (-7.87 \pm 1.72 \pm 0.93) \cdot 10^{-3}$$

is slightly in the unphysical region.

Theory prediction with new physics:

$$a_{\mathrm{fs}} = (3.2 \pm 0.6) \cdot 10^{-3} \frac{\sin \phi_d^\Delta}{|\Delta_d|} + (2.1 \pm 0.4) \cdot 10^{-3} \frac{\sin \phi_s^\Delta}{|\Delta_s|}$$

A. Lenz, UN 2011

$\Rightarrow$ The central value of

$$a_{\mathrm{fs}} = (-7.87 \pm 1.72 \pm 0.93) \cdot 10^{-3}$$

is slightly in the unphysical region.

How much of a_{fs} could come from a_{fs}^d?

With the fit results for $|\Delta_d|$ and ϕ_d^Δ one calculates

$$a_{\rm fs}^d = \left(-3.67^{+1.34}_{-0.55}\right) \cdot 10^{-3}$$

This is better than the direct measurements by Belle, BaBar and CLEO, averaging to

$$a_{\rm fs}^d = (-4.7 \pm 4.6) \cdot 10^{-3},$$

but assumes that there is no new physics in Γ_{12}^d.

With the fit results for $|\Delta_d|$ and ϕ_d^Δ one calculates

$$a_{\mathrm{fs}}^{d} = \left(-3.67^{+1.34}_{-0.55}\right) \cdot 10^{-3}$$

This is better than the direct measurements by Belle, BaBar and CLEO, averaging to

$$a_{\mathrm{fs}}^{d} = (-4.7 \pm 4.6) \cdot 10^{-3},$$

but assumes that there is no new physics in Γ_{12}^{d}.
The contribution from new physics in $\mathrm{B_d}-\overline{\mathrm{B}}_{\mathrm{d}}$ mixing to a_{fs} is therefore

$$0.594\left(-3.67^{+1.34}_{-0.55}\right) \cdot 10^{-3} = \left(-2.2^{+0.8}_{-0.2}\right) \cdot 10^{-3}$$

Next step: Identify remainder with a_{fs}^{s} and determine $\sin(\phi_s^\Delta)$.

My personal average of ϕ_s^Δ determined from CDF, DØ and LHCb measurements of $A_{\mathrm{CP}}^{\mathrm{mix}}(B_s \to J/\psi\phi)$, the LHCb measurement of $A_{\mathrm{CP}}^{\mathrm{mix}}(B_s \to J/\psi f_0)$ and the DØ dimuon asymmetry:

$$\phi_s^\Delta = -5.2^\circ \pm 8.6^\circ$$

My personal average of ϕ_s^Δ determined from CDF, DØ and LHCb measurements of $A_{\mathrm{CP}}^{\mathrm{mix}}(B_s \to J/\psi\phi)$, the LHCb measurement of $A_{\mathrm{CP}}^{\mathrm{mix}}(B_s \to J/\psi f_0)$ and the DØ dimuon asymmetry:

$$\phi_s^\Delta = -5.2^\circ \pm 8.6^\circ$$

a_{fs} predicted from this value of ϕ_s^Δ and a_{fs}^d is

$$a_{\mathrm{fs}} = \left(-2.4^{+0.9}_{-0.5}\right) \cdot 10^{-3}$$

and the DØ dimuon asymmetry exhibits an upward fluctuation of 2.5–3.0σ from this value.

New physics in Γ_{12}^{q}?

Recall the LHCb measurement

$$\frac{\Gamma_d}{\Gamma_s} = \frac{\tau_{B_s}}{\tau_{B_d}} = 0.9996 \pm 0.0201$$

in excellent agreement with the SM preciction.
Changing the Cabibbo-favoured tree-level quantity $|\Gamma_{12}^{s}|$ by opening new enhanced decay channels such as $B_s \to \tau^+\tau^-$ will spoil this ratio.

New physics in Γ_{12}^q?

Recall the LHCb measurement

$$\frac{\Gamma_d}{\Gamma_s} = \frac{\tau_{B_s}}{\tau_{B_d}} = 0.9996 \pm 0.0201$$

in excellent agreement with the SM preciction.
Changing the Cabibbo-favoured tree-level quantity $|\Gamma_{12}^s|$ by opening new enhanced decay channels such as $B_s \to \tau^+\tau^-$ will spoil this ratio.
Sizable new physics contributing equally to B_d and B_s decays causes trouble with the semileptonic branching fraction B_{SL}.

New physics in Γ_{12}^{q}?

Recall the LHCb measurement

$$\frac{\Gamma_d}{\Gamma_s} = \frac{\tau_{B_s}}{\tau_{B_d}} = 0.9996 \pm 0.0201$$

in excellent agreement with the SM preciction.

Changing the Cabibbo-favoured tree-level quantity $|\Gamma_{12}^{s}|$ by opening new enhanced decay channels such as $B_s \to \tau^+\tau^-$ will spoil this ratio.

Sizable new physics contributing equally to B_d and B_s decays causes trouble with the semileptonic branching fraction B_{SL}.

Phenomenologically, new physics in the doubly Cabibbo-suppressed quantity Γ_{12}^{d} is still allowed, but requires somewhat contrived models of new physics.

Conclusions

- The assessment of the lifetime ratio τ_{B^+}/τ_{B_d} needs better lattice calculations as the quenched results of 2001.

Conclusions

- The assessment of the lifetime ratio τ_{B^+}/τ_{B_d} needs better lattice calculations as the quenched results of 2001.
- The lifetime ratio $\frac{\tau_{B_s}}{\tau_{B_d}} = 0.9996 \pm 0.0201$ measured by LHCb is in excellent agreement with the theory expectation $\frac{\tau_{B_s}}{\tau_{B_d}} = 1^{+0.000}_{-0.004}$.

- The data on the CP phase ϕ_s^Δ extracted from the CDF, DØ and LHCb measurements of $A_{\mathrm{CP}}^{\mathrm{mix}}(B_s \to J/\psi\phi)$, the LHCb measurement of $A_{\mathrm{CP}}^{\mathrm{mix}}(B_s \to J/\psi f_0)$ and the DØ dimuon asymmetry give

$$\phi_s^\Delta = -5.2^\circ \pm 8.6^\circ$$

in agreement with SM, but the DØ dimuon asymmetry is off from the SM prediction by 3.9σ.

- The data on the CP phase ϕ_s^Δ extracted from the CDF, DØ and LHCb measurements of $A_{\rm CP}^{\rm mix}(B_s \to J/\psi\phi)$, the LHCb measurement of $A_{\rm CP}^{\rm mix}(B_s \to J/\psi f_0)$ and the DØ dimuon asymmetry give

$$\phi_s^\Delta = -5.2^\circ \pm 8.6^\circ$$

  in agreement with SM, but the DØ dimuon asymmetry is off from the SM prediction by 3.9σ.
- A fit ignoring the LHCb value for $A_{\rm CP}^{\rm mix}(B_s \to J/\psi\phi)$ would still give a consistent picture of a large negative phase ϕ_s^Δ as seen in summer 2010.

- The data on the CP phase ϕ_s^Δ extracted from the CDF, DØ and LHCb measurements of $A_{\mathrm{CP}}^{\mathrm{mix}}(B_s \to J/\psi\phi)$, the LHCb measurement of $A_{\mathrm{CP}}^{\mathrm{mix}}(B_s \to J/\psi f_0)$ and the DØ dimuon asymmetry give

  $$\phi_s^\Delta = -5.2^\circ \pm 8.6^\circ$$

  in agreement with SM, but the DØ dimuon asymmetry is off from the SM prediction by 3.9σ.
- A fit ignoring the LHCb value for $A_{\mathrm{CP}}^{\mathrm{mix}}(B_s \to J/\psi\phi)$ would still give a consistent picture of a large negative phase ϕ_s^Δ as seen in summer 2010.
- Allowing for NP phases ϕ_s^Δ and ϕ_d^Δ alleviates the tension with the DØ dimuon asymmetry to 2.5–3.0σ.

- The data on the CP phase ϕ_s^{Δ} extracted from the CDF, DØ and LHCb measurements of $A_{\rm CP}^{\rm mix}(B_s \to J/\psi\phi)$, the LHCb measurement of $A_{\rm CP}^{\rm mix}(B_s \to J/\psi f_0)$ and the DØ dimuon asymmetry give

  $$\phi_s^{\Delta} = -5.2^\circ \pm 8.6^\circ$$

  in agreement with SM, but the DØ dimuon asymmetry is off from the SM prediction by 3.9σ.
- A fit ignoring the LHCb value for $A_{\rm CP}^{\rm mix}(B_s \to J/\psi\phi)$ would still give a consistent picture of a large negative phase ϕ_s^{Δ} as seen in summer 2010.
- Allowing for NP phases ϕ_s^{Δ} and ϕ_d^{Δ} alleviates the tension with the DØ dimuon asymmetry to 2.5–3.0σ.
- Putting new physics into Γ_{12}^{s} seems impossible, new physics in Γ_{12}^{d} is ugly.

Backup Slides

The $|V_{ub}|$ puzzle

Three ways to measure $|V_{ub}|$:

- exclusive decay $B \to \pi\ell\nu$,
- inclusive decay $B \to X\ell\nu$ and
- leptonic decay $B^+ \to \tau^+\nu_\tau$.

The $|V_{ub}|$ puzzle

Three ways to measure $|V_{ub}|$:

- exclusive decay $B \to \pi\ell\nu$,
- inclusive decay $B \to X\ell\nu$ and
- leptonic decay $B^+ \to \tau^+\nu_\tau$.

Average of several BaBar and Belle measurements:

$$B^{\mathrm{exp}}(B^+ \to \tau^+\nu_\tau) \quad = \quad (1.68 \pm 0.31) \cdot 10^{-4}$$

Standard Model:

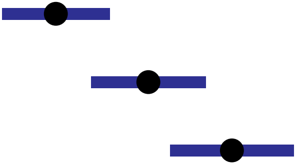
$$B(B^+ \to \tau^+\nu_\tau) \quad = \quad 1.13 \cdot 10^{-4} \cdot \left(\frac{|V_{ub}|}{4 \cdot 10^{-3}}\right)^2 \left(\frac{f_B}{200 \text{ MeV}}\right)^2$$

The $|V_{ub}|$ puzzle

$$|V_{ub,\mathrm{excl}}| = (3.51 \pm 0.47) \cdot 10^{-3}$$

$$|V_{ub,\mathrm{incl}}| = (4.32 \pm 0.50) \cdot 10^{-3}$$

$$|V_{ub,B\to\tau\nu}| = (5.10 \pm 0.59) \cdot 10^{-3}$$

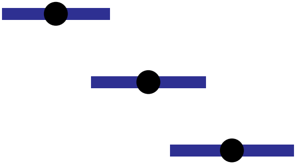


The $|V_{ub}|$ puzzle

$$|V_{ub,\mathrm{excl}}| = (3.51 \pm 0.47) \cdot 10^{-3}$$

$$|V_{ub,\mathrm{incl}}| = (4.32 \pm 0.50) \cdot 10^{-3}$$

$$|V_{ub,B\to\tau\nu}| = (5.10 \pm 0.59) \cdot 10^{-3}$$



Here $f_B = (191 \pm 13)$ MeV is used:

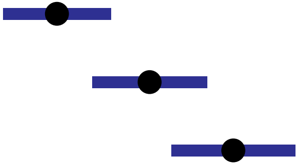
$$\begin{aligned} |V_{ub,B\to\tau\nu}| &= \left[5.10 \pm 0.47|_{\mathrm{exp}} \pm 0.35|_{\mathrm{f_B}}\right] \cdot 10^{-3} \\ &= [5.10 \pm 0.59] \cdot 10^{-3} \end{aligned}$$

The $|V_{ub}|$ puzzle

$$|V_{ub,\mathrm{excl}}| = (3.51 \pm 0.47) \cdot 10^{-3}$$

$$|V_{ub,\mathrm{incl}}| = (4.32 \pm 0.50) \cdot 10^{-3}$$

$$|V_{ub,B\to\tau\nu}| = (5.10 \pm 0.59) \cdot 10^{-3}$$



Here $f_B = (191 \pm 13)$ MeV is used:

$$\begin{aligned} |V_{ub,B\to\tau\nu}| &= \left[5.10 \pm 0.47|_{\mathrm{exp}} \pm 0.35|_{\mathrm{f_B}}\right] \cdot 10^{-3} \\ &= [5.10 \pm 0.59] \cdot 10^{-3} \end{aligned}$$

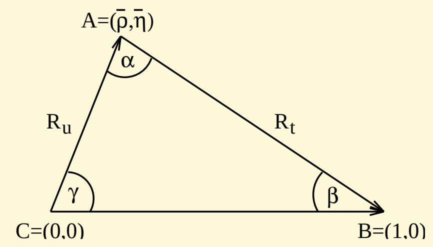
$\Rightarrow$ no puzzle with individual $|V_{ub}|$ determinations

The $|V_{ub}|$ puzzle

Indirect determination:

find $|V_{ub}| \propto |V_{cb}| R_u$

from $R_u = \dfrac{\sin\beta}{\sin\alpha}$



With $\alpha = 89^\circ{}^{+4.4^\circ}_{-4.2^\circ}$ and $\beta = 21.15^\circ \pm 0.89^\circ$ find

$$|V_{ub}|_{\text{ind}} \quad = \quad (3.41 \pm 0.15) \cdot 10^{-3}$$

Essential: β from $A_{\text{CP}}^{\text{mix}}(B_d \to J/\psi K_S)$

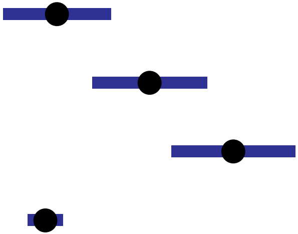
The $|V_{ub}|$ puzzle

$$|V_{ub,\mathrm{excl}}| = (3.51 \pm 0.47) \cdot 10^{-3}$$

$$|V_{ub,\mathrm{incl}}| = (4.32 \pm 0.50) \cdot 10^{-3}$$

$$|V_{ub,B\to\tau\nu}| = (5.10 \pm 0.59) \cdot 10^{-3}$$

$$|V_{ub,\mathrm{ind}}| = (3.41 \pm 0.15) \cdot 10^{-3}$$



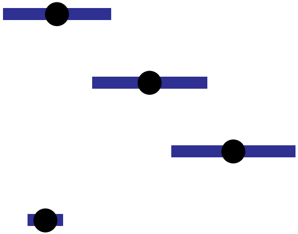
The $|V_{ub}|$ puzzle

$|V_{ub,\mathrm{excl}}| = (3.51 \pm 0.47) \cdot 10^{-3}$

$|V_{ub,\mathrm{incl}}| = (4.32 \pm 0.50) \cdot 10^{-3}$

$|V_{ub,B\to\tau\nu}| = (5.10 \pm 0.59) \cdot 10^{-3}$

$|V_{ub,\mathrm{ind}}| = (3.41 \pm 0.15) \cdot 10^{-3}$



Alleviate the 2.9σ tension between $|V_{ub,\mathrm{ind}}|$ and $|V_{ub,B\to\tau\nu}|$ with new physics in

- $B^+ \to \tau^+\nu_\tau$
  E.g. right-handed W coupling, possible in SUSY through loop effects. Crivellin 2009

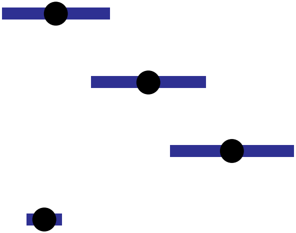
The $|V_{ub}|$ puzzle

$$|V_{ub,\mathrm{excl}}| = (3.51 \pm 0.47) \cdot 10^{-3}$$

$$|V_{ub,\mathrm{incl}}| = (4.32 \pm 0.50) \cdot 10^{-3}$$

$$|V_{ub,B\to\tau\nu}| = (5.10 \pm 0.59) \cdot 10^{-3}$$

$$|V_{ub,\mathrm{ind}}| = (3.41 \pm 0.15) \cdot 10^{-3}$$



Alleviate the 2.9σ tension between $|V_{ub,\mathrm{ind}}|$ and $|V_{ub,B\to\tau\nu}|$ with new physics in

- $B^+ \to \tau^+\nu_\tau$ or
- $A_{\mathrm{CP}}^{\mathrm{mix}}(B_d \to J/\psi K_S)$.   ← easier!