

NEW PHYSICS IN B_s -MIXING AND DECAYS

Christoph Bobeth

TU Munich – Excellence Cluster Universe

Implications of LHCb measurements
and future prospects

– B_s Mixing –

Introduction

New physics in M_{12}

... and Γ_{12}

B_q^0 -meson mixing: ΔM_q & $\Delta \Gamma_q$

Flavour eigenstates $\bar{B}_q = (b\bar{q})$ and $B_q = (\bar{b}q)$ with $q = d, s$ (PDG-convention)

TIME EVOLUTION

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

2×2 -matrices: $M^q = (M^q)^\dagger$, $\Gamma^q = (\Gamma^q)^\dagger$

CPT-invariance

$$M_{11}^q = M_{22}^q, \quad M_{12}^q = (M_{21}^q)^*, \quad \Gamma_{11}^q = \Gamma_{22}^q$$

B_q^0 -meson mixing: ΔM_q & $\Delta\Gamma_q$

Flavour eigenstates $\bar{B}_q = (b\bar{q})$ and $B_q = (\bar{b}q)$ with $q = d, s$ (PDG-convention)

TIME EVOLUTION

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

$$2 \times 2\text{-matrices: } M^q = (M^q)^\dagger, \quad \Gamma^q = (\Gamma^q)^\dagger$$

CPT-invariance

$$M_{11}^q = M_{22}^q, \quad M_{12}^q = (M_{21}^q)^*, \quad \Gamma_{11}^q = \Gamma_{22}^q$$

Heavy & light mass eigenstates B_H^q and B_L^q from diagonalisation of $(M - i\Gamma/2)$

\Rightarrow eigenvalues $M_{H,L}^q$ and $\Gamma_{L,H}^q$ (all positive)

$$M_{11} = M_{22} = \frac{M_H^q + M_L^q}{2}$$

$$\Gamma_{11} = \Gamma_{22} = \frac{\Gamma_L^q + \Gamma_H^q}{2}$$

B_q^0 -meson mixing: ΔM_q & $\Delta \Gamma_q$

Flavour eigenstates $\bar{B}_q = (b\bar{q})$ and $B_q = (\bar{b}q)$ with $q = d, s$ (PDG-convention)

TIME EVOLUTION

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

$$2 \times 2\text{-matrices: } M^q = (M^q)^\dagger, \quad \Gamma^q = (\Gamma^q)^\dagger$$

CPT-invariance

$$M_{11}^q = M_{22}^q, \quad M_{12}^q = (M_{21}^q)^*, \quad \Gamma_{11}^q = \Gamma_{22}^q$$

Heavy & light mass eigenstates B_H^q and B_L^q from diagonalisation of $(M - i\Gamma/2)$

\Rightarrow eigenvalues $M_{H,L}^q$ and $\Gamma_{L,H}^q$ (all positive)

$$M_{11} = M_{22} = \frac{M_H^q + M_L^q}{2}$$

$$\Gamma_{11} = \Gamma_{22} = \frac{\Gamma_L^q + \Gamma_H^q}{2}$$

$\Rightarrow \Delta M_q$ determines oscillation frequency

$\Rightarrow \Delta \Gamma_q$ corresponds to "damping"

2 OBSERVABLES

$$\Delta M_q = M_H^q - M_L^q = 2 |M_{12}^q| + \dots \geq 0$$

$$\Delta \Gamma_q = \Gamma_L - \Gamma_H = 2 |\Gamma_{12}^q| \cos(\phi_q) + \dots \geq 0$$

\Rightarrow 3 parameters:

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

ΔM_S from

- CDF (2006 1/fb, hadr. + semi-lept. B_s decays)
- LHCb (2011 36/pb, $B_s \rightarrow D_s^- \pi^+$)

[CDF hep-ex/0609040]

[LHCb arXiv:1112.4311]

$$\Delta M_S|_{\text{exp}} = (17.731 \pm 0.045)/ps \quad \Leftrightarrow \quad \Delta M_S|_{\text{SM}} = (17.3 \pm 2.6)/ps$$

experimental precision ahead of theory \rightarrow lattice results needed

[Lenz/Nierste arXiv:1102.4274]

ΔM_S from

- CDF (2006 1/fb, hadr. + semi-lept. B_s decays)
- LHCb (2011 36/pb, $B_s \rightarrow D_s^- \pi^+$)

[CDF hep-ex/0609040]

[LHCb arXiv:1112.4311]

$$\Delta M_S|_{\text{exp}} = (17.731 \pm 0.045)/\text{ps} \quad \Leftrightarrow \quad \Delta M_S|_{\text{SM}} = (17.3 \pm 2.6)/\text{ps}$$

experimental precision ahead of theory \rightarrow lattice results needed

[Lenz/Nierste arXiv:1102.4274]

Γ_S , $\Delta\Gamma_S$ and ϕ_f : Combined fit from $\overline{B}_s, B_s \rightarrow f$ (time-dependent + tagged)

$$\Rightarrow f = J/\psi + \phi, J/\psi + \pi\pi, \dots$$

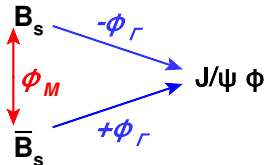
In literature several conventions of ϕ_f , for example $f = J/\psi + \phi$

- LHCb [arXiv:1112.3183]:

$$\phi_S|_{\text{SM}} = \phi_M - 2\phi_\Gamma \approx -2 \arg \left[-\frac{V_{ts} V_{tb}^*}{V_{cs} V_{cb}^*} \right] = -2\beta_S$$

- Lenz/Nierste/CKMfitter [arXiv:1203.0238]:

$$2\phi_S^{\psi\phi}|_{\text{SM}} = 2\beta_S = (2.1 \pm 0.1)^\circ$$



ΔM_S from

- CDF (2006 1/fb, hadr. + semi-lept. B_s decays)
- LHCb (2011 36/pb, $B_s \rightarrow D_s^- \pi^+$)

[CDF hep-ex/0609040]

[LHCb arXiv:1112.4311]

$$\Delta M_S|_{\text{exp}} = (17.731 \pm 0.045)/ps \quad \Leftrightarrow \quad \Delta M_S|_{\text{SM}} = (17.3 \pm 2.6)/ps$$

experimental precision ahead of theory \rightarrow lattice results needed

[Lenz/Nierste arXiv:1102.4274]

$\Gamma_S, \Delta\Gamma_S$ and ϕ_f : Combined fit from $\overline{B}_s, B_s \rightarrow f$ (time-dependent + tagged)

$-2\phi_s^{\psi\phi} = (-44_{-21}^{+17})^\circ$	CDF 1.35/fb and DØ 2.8/fb [HFAG 2011]
$= (-43.5_{-20.6}^{+21.8} \pm 1.2)^\circ$	DØ 6.1/fb [Conference Note 6098]
$\in [-59.6, -2.3]^\circ$	CDF 5.2/fb [arXiv:1112.1726]
$= (8.6 \pm 10.3 \pm 3.4)^\circ$	LHCb 0.37/fb ($\rightarrow J/\psi \phi$) [arXiv:1112.3183]
$= (-25.2 \pm 25.2 \pm 1.2)^\circ$	LHCb 0.41/fb ($\rightarrow J/\psi f_0$) [arXiv:1112.3056]
$= (-0.06 \pm 5.79 \pm 1.55)^\circ$	LHCb 1/fb ($\rightarrow J/\psi \phi$) [LHCb-CONF-2012-002]
$= (-1.1 \pm 9.7 \pm 1.1)^\circ$	LHCb 1/fb ($\rightarrow J/\psi f_0$) [LHCb-CONF-2012-006]
$= (-0.11 \pm 4.76 \pm 1.55)^\circ$	LHCb 1/fb combined $\rightarrow J/\psi \phi$ and $\rightarrow J/\psi f_0$

$$-2\phi_s^{\psi\phi}|_{\text{SM}} = (-2.1 \pm 0.1)^\circ$$

CP-asymmetries: $a_{fs}^{d,s}$ & A_{SL}^b

a_{fs}^q = CP-asym's in flavour specific $B_q \rightarrow f$

$$a_{fs}^q = \frac{\Gamma[\overline{B}_q(t) \rightarrow f] - \Gamma[B_q(t) \rightarrow \bar{f}]}{\Gamma[\overline{B}_q(t) \rightarrow f] + \Gamma[B_q(t) \rightarrow \bar{f}]} = \frac{|\Gamma_{12}^q|}{|M_{12}^q|} \sin(\phi_q)$$

CP-asymmetries: $a_{fs}^{d,s}$ & A_{SL}^b

a_{fs}^q = CP-asym's in flavour specific $B_q \rightarrow f$

$$a_{fs}^q = \frac{\Gamma[\overline{B}_q(t) \rightarrow f] - \Gamma[B_q(t) \rightarrow \bar{f}]}{\Gamma[\overline{B}_q(t) \rightarrow f] + \Gamma[B_q(t) \rightarrow \bar{f}]} = \frac{|\Gamma_{12}^q|}{|M_{12}^q|} \sin(\phi_q)$$

Like-sign dimuon charge asymmetry
of semi-leptonic b -hadron decays

$$A_{SL}^b = \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}$$

$N_b^{++(--)}$ = # of evts with 2 μ^+ (μ^-)

CP-asymmetries: $a_{fs}^{d,s}$ & A_{SL}^b

a_{fs}^q = CP-asym's in flavour specific $B_q \rightarrow f$

$$a_{fs}^q = \frac{\Gamma[\overline{B}_q(t) \rightarrow f] - \Gamma[B_q(t) \rightarrow \bar{f}]}{\Gamma[\overline{B}_q(t) \rightarrow f] + \Gamma[B_q(t) \rightarrow \bar{f}]} = \frac{|\Gamma_{12}^q|}{|M_{12}^q|} \sin(\phi_q)$$

Like-sign dimuon charge asymmetry of semi-leptonic b -hadron decays

$$A_{SL}^b = \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}$$

$N_b^{++(--)}$ = # of evts with 2 μ^+ (μ^-)

$$A_{SL}^b = C_d a_{fs}^d + C_s a_{fs}^s$$

C_q depend on production rate of B_q

A_{SL}^b relates B_d - and B_s -mixing !!!

$$C_d \approx 0.55 \quad , \quad C_s \approx 0.45$$

CP-asymmetries: $a_{fs}^{d,s}$ & A_{SL}^b

a_{fs}^q = CP-asym's in flavour specific $B_q \rightarrow f$

$$a_{fs}^q = \frac{\Gamma[\overline{B}_q(t) \rightarrow f] - \Gamma[B_q(t) \rightarrow \bar{f}]}{\Gamma[\overline{B}_q(t) \rightarrow f] + \Gamma[B_q(t) \rightarrow \bar{f}]} = \frac{|\Gamma_{12}^q|}{|M_{12}^q|} \sin(\phi_q)$$

Like-sign dimuon charge asymmetry of semi-leptonic b -hadron decays

$$A_{SL}^b = \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}$$

$N_b^{+(-)}$ = # of evts with 2 μ^+ (μ^-)

$$A_{SL}^b = C_d a_{fs}^d + C_s a_{fs}^s$$

C_q depend on production rate of B_q

A_{SL}^b relates B_d - and B_s -mixing !!!

$C_d \approx 0.55$, $C_s \approx 0.45$

A_{SL}^b : $D\bar{D}$ (9/fb) measurement deviates by 3.9σ from SM

a_{fs}^q : measurements with large errors

SM = [Lenz/Nierste arXiv:1102.4274]

$[\times 10^{-3}]$	SM	measurement	
A_{SL}^b	-0.24 ± 0.04	$-7.87 \pm 1.72 \pm 0.93$	[$D\bar{D}$ arXiv:1106.6308]
a_{fs}^d	-0.41 ± 0.06	-4.7 ± 4.6 -0.5 ± 5.6	[HFAG arXiv:1010.1589] (B -factories) [HFAG 2011] (B -factories)
a_{fs}^s	-0.019 ± 0.003	-1.7 ± 9.2	[$D\bar{D}$ arXiv:0904.3907]

In the SM ...

$$M_{12} = \left[\begin{array}{c} \text{Diagram of } M_{12} \text{ box} \end{array} \right] \Rightarrow$$

The diagram for M_{12} shows a box with two yellow ovals on the left and right, labeled B_s and \overline{B}_s respectively. On the left, two quark lines enter: a top quark t (blue arrow pointing up) and an anti-top quark \bar{t} (blue arrow pointing down). On the right, two quark lines exit: a top quark t (blue arrow pointing down) and an anti-top quark \bar{t} (blue arrow pointing up). Two wavy green lines, representing W bosons, connect the top and anti-top quark lines. The top quark line is labeled b at the top and s at the bottom. The anti-top quark line is labeled s at the top and b at the bottom.

$$G_i \times \left[\begin{array}{c} \text{Diagram of } G_i \text{ box} \end{array} \right]$$

The diagram for G_i shows a box with two yellow ovals on the left and right, labeled B_s and \overline{B}_s respectively. On the left, two quark lines enter: a top quark t (black arrow pointing up) and an anti-top quark \bar{t} (black arrow pointing down). On the right, two quark lines exit: a top quark t (black arrow pointing down) and an anti-top quark \bar{t} (black arrow pointing up). A small blue square represents a vertex connecting the top and anti-top quark lines.

$$\Gamma_{12} = \text{Im} \left[\begin{array}{c} \text{Diagram of } \Gamma_{12} \text{ box} \end{array} \right] \Rightarrow$$

The diagram for Γ_{12} shows a box with two yellow ovals on the left and right, labeled B_s and \overline{B}_s respectively. On the left, two quark lines enter: a charm quark c (red arrow pointing up) and an anti-charm quark \bar{c} (red arrow pointing down). On the right, two quark lines exit: a charm quark c (red arrow pointing down) and an anti-charm quark \bar{c} (red arrow pointing up). Two wavy green lines, representing W bosons, connect the charm and anti-charm quark lines. The charm quark line is labeled b at the top and s at the bottom. The anti-charm quark line is labeled s at the top and b at the bottom.

$$C_a C_b^* \times \text{Im} \left[\begin{array}{c} \text{Diagram of } C_a C_b^* \text{ box} \end{array} \right]$$

The diagram for $C_a C_b^*$ shows a box with two yellow ovals on the left and right, labeled B_s and \overline{B}_s respectively. On the left, two quark lines enter: a charm quark c (black arrow pointing up) and an anti-charm quark \bar{c} (black arrow pointing down). On the right, two quark lines exit: a charm quark c (black arrow pointing down) and an anti-charm quark \bar{c} (black arrow pointing up). Two orange squares represent vertices connecting the charm and anti-charm quark lines. A red circle with arrows connects the two orange squares, representing a loop of u, c quarks.

In the SM ...

$$M_{12} = \left[\begin{array}{c} \text{Diagram: } B_s \text{ and } \bar{B}_s \text{ mesons connected by two } W \text{ bosons and } t \text{ quarks.} \\ \text{Left meson } B_s \text{ (yellow oval), right meson } \bar{B}_s \text{ (yellow oval).} \\ \text{Top quark lines: } b \text{ (left) and } s \text{ (right).} \\ \text{Bottom quark lines: } s \text{ (left) and } b \text{ (right).} \\ \text{Two } W \text{ bosons (green wavy lines) connect the quarks.} \\ \text{Two } t \text{ quarks (blue vertical lines) are exchanged between the } W \text{ bosons.} \end{array} \right] \Rightarrow G_i \times \left[\begin{array}{c} \text{Diagram: } B_s \text{ and } \bar{B}_s \text{ mesons connected by a blue square vertex.} \\ \text{Left meson } B_s \text{ (yellow oval), right meson } \bar{B}_s \text{ (yellow oval).} \\ \text{Top quark lines: } b \text{ (left) and } s \text{ (right).} \\ \text{Bottom quark lines: } s \text{ (left) and } b \text{ (right).} \end{array} \right]$$

$$\Delta B = 2 \sim M_W^2 / \Lambda_{\text{NP}}^2$$

$$\Gamma_{12} = \text{Im} \left[\begin{array}{c} \text{Diagram: } B_s \text{ and } \bar{B}_s \text{ mesons connected by two } W \text{ bosons and } u, c \text{ quarks.} \\ \text{Left meson } B_s \text{ (yellow oval), right meson } \bar{B}_s \text{ (yellow oval).} \\ \text{Top quark lines: } b \text{ (left) and } s \text{ (right).} \\ \text{Bottom quark lines: } s \text{ (left) and } b \text{ (right).} \\ \text{Two } W \text{ bosons (green wavy lines) connect the quarks.} \\ \text{Two } u, c \text{ quarks (red vertical lines) are exchanged between the } W \text{ bosons.} \end{array} \right] \Rightarrow C_a C_b^* \times \text{Im} \left[\begin{array}{c} \text{Diagram: } B_s \text{ and } \bar{B}_s \text{ mesons connected by a red loop.} \\ \text{Left meson } B_s \text{ (yellow oval), right meson } \bar{B}_s \text{ (yellow oval).} \\ \text{Top quark lines: } b \text{ (left) and } s \text{ (right).} \\ \text{Bottom quark lines: } s \text{ (left) and } b \text{ (right).} \\ \text{A red loop connects the } W \text{ bosons, labeled } u, c. \end{array} \right]$$

$$(\Delta B = 1)^2 \sim M_W^4 / \Lambda_{\text{NP}}^4$$

For heavy new physics ($M_W \lesssim \Lambda_{\text{NP}}$) \rightarrow can be described by dim-6 op's

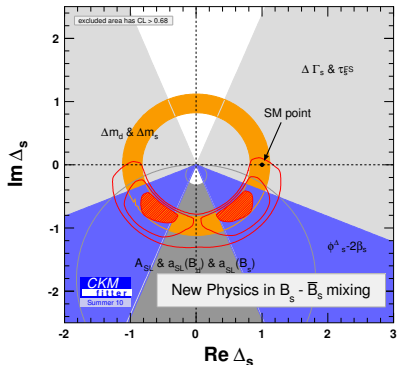
- $\Delta B = 2 \rightarrow [\bar{s}\Gamma b][\bar{s}\Gamma' b]$
- $\Delta B = 1 \rightarrow [\bar{s}\Gamma b][\bar{f}_1\Gamma' f_2]$ with " $(m_{f_1} + m_{f_2}) \lesssim M_{B_s}$ " $\Rightarrow f = (u, d, s, c)$ and (e, μ, τ)
(or BSM $f = ???$)

- perform global CKM-fit
- use parametrisation of New Physics (NP) in:

$$M_{12}^q = M_{12}^{\text{SM},q} \cdot \Delta_q, \quad \Delta_q = |\Delta_q| e^{i\phi_q^{\Delta}}, \quad q = d, s$$

- 2 complex NP parameters \rightarrow 4 dimensional NP parameter space
- B_d - and B_s -sector connected via A_{SL}^b

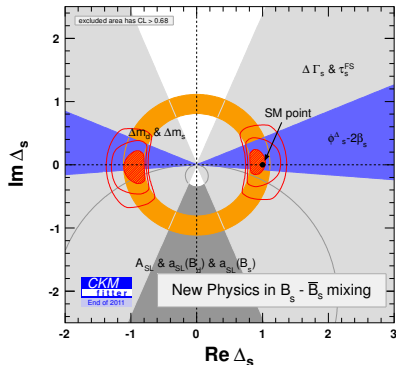
New physics in M_{12}^S : 2010 vs 02/2012 [Lenz/Nierste/CKMfitter arXiv:1008.1593, arXiv:1203.0238]



2010

p -value for hypothesis $\Delta_s = 1$ (2D)

2.7σ

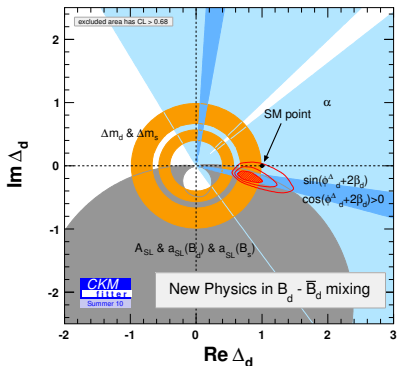


02/2012 (before Moriond)

0.8σ

⇒ tension with SM in B_s -system gone due to new $\phi_s^{\psi\phi}$ measurements of LHCb

New physics in M_{12}^d : 2010 vs 02/2012 [Lenz/Nierste/CKMfitter arXiv:1008.1593, arXiv:1203.0238]



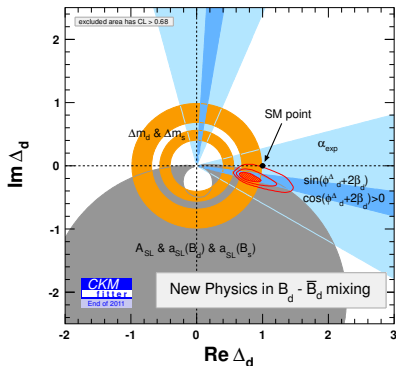
2010

p -value for hypothesis $\Delta_d = 1$ (2D)

2.7σ

for SM hypothesis $\Delta_d = \Delta_s = 1$ (4D)

3.6σ



02/2012 (before Moriond)

3.2σ

2.7σ

⇒ tension in B_d -system augmented, but overall tension with SM decreased

New physics in Γ_{12}^q :

[Lenz/Nierste/CKMfitter arXiv:1008.1593, arXiv:1203.0238]

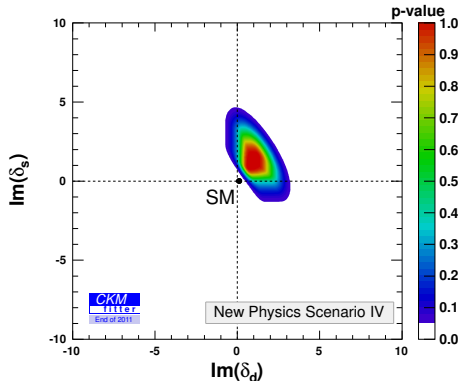
Model-ind. parametrisation of NP in Γ_{12}^q

$$\delta_q = \frac{\Gamma_{12}^q / M_{12}^q}{\text{Re} \left(\Gamma_{12}^{\text{SM},q} / M_{12}^{\text{SM},q} \right)}$$

but does NOT account for NP in $\Delta B = 1$ decays

$$\delta_d^{\text{SM}} = 1 + 0.097 i$$

$$\delta_s^{\text{SM}} = 1 - 0.0059 i$$



- p -value of SM hypothesis

$$(\Delta_d = \Delta_s = 1, \delta_q = \delta_q^{\text{SM}}) :$$

$$2.7 \sigma$$

- no NP in B_s ($\Delta_s = 1, \delta_s = \delta_s^{\text{SM}}$)

gives large contributions in Γ_{12}^d :

$$\text{Im } \delta_d = 1.48^{+0.92}_{-0.65}$$

New physics in $\Gamma_{12}^s \dots$

\dots using $\Delta B = 1$ operators $\mathcal{O}_i = [\bar{s}\Gamma b][\bar{f}_1\Gamma'f_2]$ with light $f_{1,2}$

$$\Gamma_{12} = \Gamma_{12}^{\text{SM}} + C_a C_b^* \times \text{Im} \left[\text{Diagram} \right]$$

\Rightarrow subject to constraints since contribute to: $\Gamma_s, \tau(B_s)/\tau(B_d), b \rightarrow s \bar{f}_1 f_2$ decays ...

New physics in $\Gamma_{12}^s \dots$

... using $\Delta B = 1$ operators $\mathcal{O}_i = [\bar{s}\Gamma b][\bar{f}_1\Gamma'f_2]$ with light $f_{1,2}$

$$\Gamma_{12} = \Gamma_{12}^{\text{SM}} + C_a C_b^* \times \text{Im} \left[\begin{array}{c} b \qquad f_2 \qquad s \\ \swarrow \quad \searrow \quad \swarrow \\ \text{[} B_s \text{]} \quad \text{[} Q_a \text{]} \quad \text{[} Q_b \text{]} \quad \text{[} \bar{B}_s \text{]} \\ \nwarrow \quad \swarrow \quad \nwarrow \\ s \qquad f_1 \qquad b \end{array} \right]$$

⇒ subject to constraints since contribute to: Γ_s , $\tau(B_s)/\tau(B_d)$, $b \rightarrow s \bar{f}_1 f_2$ decays ...

... from $b \rightarrow s \tau^+ \tau^-$: [Dighe/Kundu/Nandi arXiv:0705.4547, Bauer/Dunn 1006.1629, CB/Haisch 1109.1826]

Could be a candidate → **only weak direct constraints**:

- $Br(B^+ \rightarrow K^+ \tau^+ \tau^-) < 3.3 \cdot 10^{-3}$ @ 90% CL [Babar @ ICHEP 2010]
- $Br(B_s \rightarrow \tau^+ \tau^-) \lesssim 3\%$ @ 90% CL only indirectly from $\tau(B_s)/\tau(B_d)$
 - assuming no NP in $\tau(B_d)$
 - based on LHCb measurement: $\tau(B_s)/\tau(B_d) - 1 = (0.4 \pm 1.9)\%$ [LHCb-CONF-2011-049]
 - SM prediction: $\in [-0.4, 0.0]\%$ [Lenz/Nierste 1102.4274]
- $Br(B \rightarrow X_s \tau^+ \tau^-) \lesssim 5\%$ LEP: B decays with large E [Grossman/Ligeti/Nardi hep-ph/9607473]
- $Br(B \rightarrow X_s \tau^+ \tau^-) \lesssim 2.5\%$ → bckg to $Br(B \rightarrow K \ell \bar{\nu}_\ell + \text{anything}) = (4 \dots 6 \pm 0.5) \cdot 10^{-2}$

New physics in Γ_{12}^s ...

... using $\Delta B = 1$ operators $\mathcal{O}_i = [\bar{s}\Gamma b][\bar{f}_1\Gamma' f_2]$ with light $f_{1,2}$

$$\Gamma_{12} = \Gamma_{12}^{\text{SM}} + C_a C_b^* \times \text{Im} \left[\text{Diagram} \right]$$

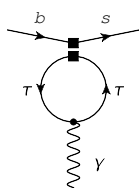
\Rightarrow subject to constraints since contribute to: Γ_s , $\tau(B_s)/\tau(B_d)$, $b \rightarrow s \bar{f}_1 f_2$ decays ...

... from $b \rightarrow s \tau^+ \tau^-$:

[CB/Haisch arXiv:1109.1826]

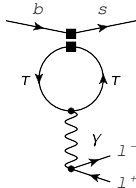
Also **indirect constraints** due to operator mixing

Used measurements



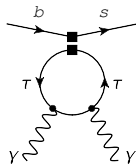
$$\mathcal{O}_{TR} \rightarrow \mathcal{O}_7$$

$$\mathcal{O}_{TL} \rightarrow \mathcal{O}_{7'}$$



$$\mathcal{O}_{VLA} \rightarrow \mathcal{O}_9$$

$$\mathcal{O}_{VRA} \rightarrow \mathcal{O}_{9'}$$



$$\mathcal{O}_{SAB} \rightarrow \vec{\epsilon}_1 \cdot \vec{\epsilon}_2$$

$$\mathcal{O}_{SAB}, \mathcal{O}_{VAB} \rightarrow \vec{\epsilon}_1 \times \vec{\epsilon}_2$$

$$B \rightarrow X_s \gamma: \quad Br$$

$$B \rightarrow K^* \gamma: \quad Br, S, A_l$$

$$B_s \rightarrow \gamma \gamma: \quad Br$$

$$B \rightarrow X_s \bar{l} l: \quad \langle BR \rangle \text{ (low-} q^2 \text{)}$$

$$B \rightarrow K \bar{l} l: \quad \langle BR \rangle$$

$$B \rightarrow K^* \bar{l} l: \quad \langle BR \rangle, \langle A_{\text{FB}} \rangle, \langle F_L \rangle$$

SAB op's neither mix into $b \rightarrow s \gamma$ nor $b \rightarrow s \bar{l} l$, but contribute to ME of $b \rightarrow s \gamma \gamma$

New physics in $\Gamma_{12}^s \dots$

\dots using $\Delta B = 1$ operators $\mathcal{O}_i = [\bar{s}\Gamma b][\bar{f}_1\Gamma'f_2]$ with light $f_{1,2}$

$$\Gamma_{12} = \Gamma_{12}^{\text{SM}} + C_a C_b^* \times \text{Im} \left[\begin{array}{c} b \quad f_2 \quad s \\ \swarrow \quad \searrow \quad \swarrow \\ \text{[} B_s \text{]} \quad \text{[} Q_a \text{]} \quad \text{[} Q_b \text{]} \quad \text{[} \bar{B}_s \text{]} \\ \nwarrow \quad \swarrow \quad \nwarrow \\ s \quad f_1 \quad b \end{array} \right]$$

\Rightarrow subject to constraints since contribute to: $\Gamma_s, \tau(B_s)/\tau(B_d), b \rightarrow s \bar{f}_1 f_2$ decays ...

\dots from $b \rightarrow s \tau^+ \tau^-$:

[CB/Haisch arXiv:1109.1826 update]

Upper bounds assuming single operator dominance and complex C_i :

$ C_i(m_b) $	$B_s \rightarrow \bar{\tau}\tau$	$B \rightarrow X_s \bar{\tau}\tau$	$B^+ \rightarrow K^+ \bar{\tau}\tau$	bound	ind. process
SAL	< 0.5	< 2.9	< 0.8	< 3.4	$B_s \rightarrow \gamma\gamma$
SAR				< 2.3	"
VAL	< 1.0	< 1.5	< 0.8	< 1.1	$b \rightarrow s + (\gamma, \bar{\ell}\ell)$
VAR				< 1.0	"
TL		< 0.4	< 0.4	< 0.06	"
TR	-			< 0.09	"

$\mathcal{O}_{XAB} = [\bar{s} X P_A b][\bar{\tau} X P_B \tau]$ with $X = (S = 1, V = \gamma^\mu, T = \sigma^{\mu\nu})$

$A, B = L, R$ and $P_{L,R} = (1 \mp \gamma_5)/2$

New physics in $\Gamma_{12}^s \dots$

... using $\Delta B = 1$ operators $\mathcal{O}_i = [\bar{s}\Gamma b][\bar{f}_1\Gamma'f_2]$ with light $f_{1,2}$

$$\Gamma_{12} = \Gamma_{12}^{\text{SM}} + C_a C_b^* \times \text{Im} \left[\text{Diagram} \right]$$

⇒ subject to constraints since contribute to: Γ_s , $\tau(B_s)/\tau(B_d)$, $b \rightarrow s \bar{f}_1 f_2$ decays ...

... from $b \rightarrow s \tau^+ \tau^-$:

NP contribution to $\Gamma_{12}^s = (\Gamma_{12}^s)_{\text{SM}} R_\Gamma e^{i\phi_\Gamma}$

Assuming single operator dominance

$$(R_\Gamma)_{SAB} < 1 + (0.4 \pm 0.1) |C_{SAB}(m_b)|^2 \lesssim 1.15$$

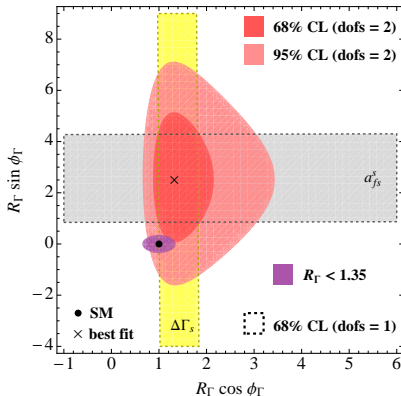
$$(R_\Gamma)_{VAB} < 1 + (0.4 \pm 0.1) |C_{VAB}(m_b)|^2 \lesssim 1.35$$

$$(R_\Gamma)_{TA} < 1 + (0.9 \pm 0.2) |C_{TA}(m_b)|^2 \lesssim 1.008$$

⇒ at most 35% deviation from SM: $R_\Gamma = 1$

(in fit a_{fs}^s calculated from experimental A_{SL}^b and a_{fs}^d)

[CB/Haisch arXiv:1109.1826 update]



- Assuming New Physics in B_q -mixing improves the fit compared to SM
- Including LHCb results (before Moriond) ($\Delta\Gamma_s, \phi_s^{\psi\phi}$) helps SM ‘performance’ in B_s -sector
- $D\bar{D}$ measurement of A_{SL}^b connects B_d - and B_s -sectors
→ SM more “in trouble” in B_d -sector
- New physics in Γ_{12}^q can help, however in $q = s$ many strong constraints
→ Γ_{12}^d not so strongly constraint
- Despite the loose constraints on $b \rightarrow s \tau^+ \tau^-$, allow only about $\mathcal{O}(30\%)$ deviation of Γ_{12}^s from SM

SUMMARY 2/2

- Pursue a measurement of a_{fs}^d , a_{fs}^s or linear combination ($a_{fs}^s - a_{fs}^d$)
- Improve measurement of life-times
- Independent bound on $B_s \rightarrow \tau^+ \tau^-$ could be useful
- In view of future high precision in $\phi_s^{\psi\phi}$,
→ penguin pollution in $B_s \rightarrow J/\psi\phi$ or $B_s \rightarrow J/\psi(\pi\pi)$

use control channels

$$B_s \rightarrow J/\psi K^{*0} \quad [\text{Faller/Fleischer/Mannel arXiv:0810.4248}]$$

$$B_d \rightarrow J/\psi f_0 \quad [\text{Fleischer/Knegjens/Ricciardi arXiv:1109.1112}]$$

- Measure penguin-dominated $B_{s,d}(\rightarrow \phi\phi, K^{*0}\bar{K}^{*0}, \phi K_S^0, \dots)$ decays to learn about possible NP-phases
→ penguin pollution in $B_s \rightarrow J/\psi\phi$ or $B_s \rightarrow J/\psi(\pi\pi)$