B mixing in the Standard Model and beyond

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Outline

- Introduction
- The Standard Model (SM)
- Beyond the SM

Introduction to

B mixing

Neutral B_q-meson mixing

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

Time evolution

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

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

Assuming CPT-invariance

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

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$$M^q_{11} = M^q_{22}, \qquad M^q_{12} = (M^q_{21})^*, \qquad \Gamma^q_{11} = \Gamma^q_{22}$$

Heavy & light mass eigenstates B^q_H and B^q_L from diagonalisation of $(M - i\Gamma/2)$

$\Rightarrow$ eigenvalues $M^q_{H,L}$ and $\Gamma^q_{L,H}$ (all positive)

$$M_{11} = M_{22} = \frac{M^q_H + M^q_L}{2}$$

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$\Rightarrow$ ΔM_q determines oscillation frequency

$\Rightarrow$ $\Delta\Gamma_q$ corresponds to “damping”

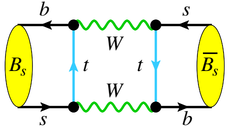
$$\Delta M_q = M^q_H - M^q_L = 2\,|M^q_{12}| + \ldots \geq 0$$

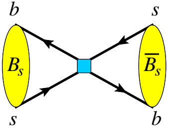
$$\Delta\Gamma_q = \Gamma_L - \Gamma_H = 2\,|\Gamma^q_{12}|\cos(\zeta_q) + \ldots \gtrless 0$$

are related to

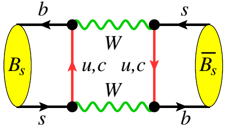
$$|M^q_{12}|, \qquad |\Gamma^q_{12}|, \qquad \zeta_q = \arg\left(-\frac{M^q_{12}}{\Gamma^q_{12}}\right)$$

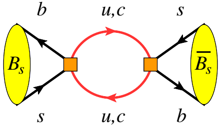
In the SM . . .

$M_{12}^q = \Big[$ 

$\Big] \Rightarrow C_i \times \Big[$ 

$\Big]$

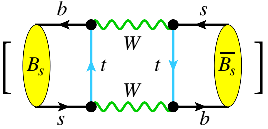
$\Gamma_{12}^q = \mathrm{Im}\Big[$ 

$\Big] \Rightarrow C_a C_b^* \times \mathrm{Im}\Big[$ 

$\Big]$

In the SM … Beyond SM … ⇒ $\Delta B = 2$ most senstive to NP

$M_{12}^q =$



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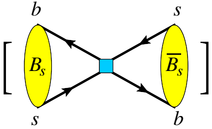
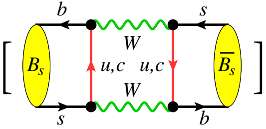
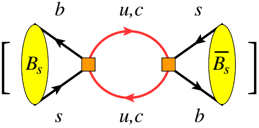


$$\Delta B = 2 \sim \left|A^{\rm SM}_{\Delta B=2}\right| \times \left(1 + \frac{(V_{\rm NP})^2}{(V_{ts})^2}\frac{M_W^2}{\Lambda_{\rm NP}^2}\right)$$

$\Gamma_{12}^q = \mathrm{Im}$



⇒ $C_a C_b^* \times \mathrm{Im}$



$$(\Delta B = 1)^2 \sim \left|A^{\rm SM}_{\Delta B=1}\right|^2 \times \left(1 + \frac{V_{\rm NP}}{V_{ts}}\frac{M_W^2}{\Lambda_{\rm NP}^2} + \ldots\right)$$

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

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

Flavour-specific CP-asymmetries (semi-leptonic CP asy's)

Provide further information on M_{12}^q and Γ_{12}^q ... measured in semi-leptonic decays $B_q \to X\ell\nu_\ell$

$$a_{\rm fs}^q = a_{\rm sl}^q = \frac{\Gamma(\overline{B}_q(t) \to f) - \Gamma(B_q(t) \to \bar{f})}{\Gamma(\overline{B}_q(t) \to f) + \Gamma(B_q(t) \to \bar{f})} = \left|\frac{\Gamma_{12}^q}{M_{12}^q}\right| \sin(\zeta_q)$$

$\Rightarrow$ measures of CP-violation in mixing: $1 - a_{\rm fs}^q = |q/p|^2 \neq 1$

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Relation to like-sign dimuon asymmetry $A_{\rm CP}$

Example of DØ: $p\bar{p} \to b\bar{b} + X$ with mixing gives $\bar{b} \to B_q \to \overline{B}_q \to \mu^-$ "wrong sign" μ

- Measure "raw asymmetries" including not just b $$A = \frac{N(\mu^+\mu^+) - N(\mu^-\mu^-)}{N(\mu^+\mu^+) + N(\mu^-\mu^-)}$$
- subtract all non-b background $A_{{\rm bkg},\not b}$ measured with same data $$A_{\rm CP} = A - A_{{\rm bkg},\not b}$$
- $A_{\rm CP}$ receives contribution from mixing $A_{\rm sl}^b = C_d a_{\rm fs}^d + C_s a_{\rm fs}^s$

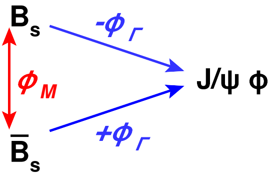
$$A_{\rm CP} = A_{\rm sl}^b + C_{\Gamma_d}\frac{\Delta\Gamma_d}{\Gamma_d} + C_{\Gamma_s}\frac{\Delta\Gamma_s}{\Gamma_s}$$

and interference in decays (example: $B_d(\overline{B}_d) \to D^{(*)+}D^{(*)-}$) [Borissov/Hoeneisen arXiv:1303.0175] [DØ arXiv:1310.0447]

- $C_d = F(f_{d,s}, \chi_{d,s})$, $C_s = 1 - C_d$ ($C_d \approx C_s \approx 0.5$) with χ_q mean mixing prob's, f_q production fractions of B_q
- C_{Γ_d} (see details arXiv:1310.0447) gives negative contribution to $A_{\rm CP}$, C_{Γ_s} negligible contribution to $A_{\rm CP}$

Time-dependent CP asy's for $\overline{B}_q, B_q \to f_{CP}$ to CP eigenstates

Mixing also interferes with CP violation in neutral B-meson decays
$\Rightarrow$ further information on $M_{12}^q = |M_{12}^q| \exp(i\,\phi_M^q)$



$$a_{CP}(t) = \frac{\Gamma(\overline{B}_q(t) \to f_{CP}) - \Gamma(B_q(t) \to f_{CP})}{\Gamma(\overline{B}_q(t) \to f_{CP}) + \Gamma(B_q(t) \to f_{CP})}$$

$$= \frac{A_{\rm mix} \sin(\Delta M\, t) - A_{\rm dir} \cos(\Delta M\, t)}{\cosh(\Delta\Gamma/2\, t) - A_{\Delta\Gamma} \sinh(\Delta\Gamma/2\, t)}$$

with 3 CP asymmetries
$$A_{\rm dir} = \frac{1 - |\lambda_f|^2}{1 + |\lambda_f|^2}, \qquad A_{\rm mix} = \frac{2\,{\rm Im}\lambda_f}{1 + |\lambda_f|^2}, \qquad A_{\Delta\Gamma} = \frac{2\,{\rm Re}\lambda_f}{1 + |\lambda_f|^2},$$

and
$$\lambda_f = \frac{q}{p}\frac{\bar{A}_f}{A_f}, \qquad \frac{q}{p} \approx -\frac{(M_{12}^q)^*}{|M_{12}^q|}, \qquad 1 = |A_{\rm dir}|^2 + |A_{\rm mix}|^2 + |A_{\Delta\Gamma}|^2$$

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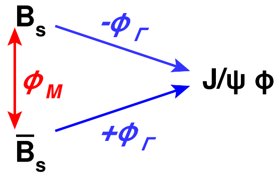

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$\Rightarrow$ Combined fits of Γ_q, $\Delta\Gamma_q$ and $\lambda_f = |\lambda_f|\exp(i\,\phi_f)$ (talks K-F. Chen, R. Fleischer, K. De Bruyn)

Golden-plated modes $|\lambda_f| \approx 1$, $A_{\rm dir} = 0$ and $A_{\rm mix} = {\rm Im}\lambda_f$: for example $B_s \to J/\psi\phi$, $J/\psi\,\pi\pi$

In literature several conventions for ϕ_f, for example $f_{CP} = J/\psi\phi$

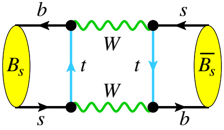
- $\phi_s|_{\rm SM} = \phi_M - 2\phi_\Gamma \approx -2\arg\left(\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right) = -2\beta_s$ [LHCb arXiv:1112.3183 ...]
- $2\phi_s^{J/\psi\phi}|_{\rm SM} = 2\beta_s = (2.1 \pm 0.1)^\circ = (0.036 \pm 0.001)$ rad [Lenz/Nierste/CKMfitter arXiv:1203.0238 ...]

Standard Model

Theory predictions of $M_{12}^q \longrightarrow \Delta M_q = 2\,|M_{12}^q|$

Short-distance (decoupling of W's and top's in box diagrams) + local matrix element

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



- Short-distance under control

  1-loop result $S_0(x_t = m_t^2/m_W^2)$ [Inami/Lim Prog.Theor.Phys. 65 (1981) 297]
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- Hadronic matrix element $\langle \bar{B}_q|(\bar{b}q)_{V-A}(\bar{b}q)_{V-A}|B_q\rangle = \frac{8}{3} B_{B_q} f_{B_q}^2 M_{B_q}$

  $\Rightarrow$ preciser Lattice results become available (talk A. Jütter) [averages from FLAG arXiv:1310.8555]

[MeV]	$N_f = 2+1$	$\delta(\Delta M_q)$		$N_f = 2+1$	$\delta(\Delta M_q)$
f_{B_s}	227.7 ± 4.5	4.0%	$\hat{B}_{B_s}$	1.33 ± 0.06	4.5%
f_{B_d}	190.5 ± 4.2	4.4%	$\hat{B}_{B_d}$	1.27 ± 0.10	7.9%

- and CKM we would like to determine from experiment . . .
  . . . and confront with tree-fit (semileptonic, $B \to D^{(*)}K$) results

  $\Rightarrow$ however, when taking UTfit tree-fit (pre-Moriond 2013): [www.utfit.org]
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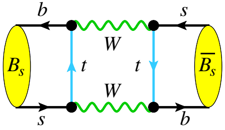

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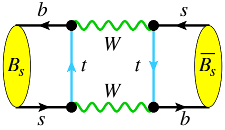

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Theoretical predictions of Γ_{12}^q

Based on Heavy Quark Expansion (HQE) = local OPE, used also for $\Delta B = 0$

$\lambda = \Lambda_{\text{QCD}}/m_b$

$$\Gamma_{12}^q = \lambda^3\left(\Gamma_3^{(0)} + \frac{\alpha_s}{4\pi}\Gamma_3^{(1)}\right) + \lambda^4\left(\Gamma_4^{(0)} + \ldots\right) + \lambda^5\left(\Gamma_5^{(0)} + \ldots\right) + \ldots$$

[Beneke/Buchalla hep-ph/9605259; Beneke/Buchalla/Greub/Lenz/Nierste 9808385; Beneke/Buchalla/Lenz/Nierste 0307344; Ciuchini/Franco/Lubicz/Mescia/Tarantino 0308029; Lenz/Nierste 0612167; Badin/Gabiani/Petrov arXiv:0707.0294]

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SM prediction [Lenz/Nierste arXiv:1102.4274]

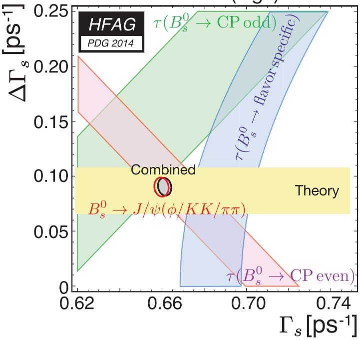
Experimental result [HFAG 2014]

$$\Delta\Gamma_s^{\text{SM}} = (0.087 \pm 0.021)\,\text{ps}^{-1}$$
$$\Delta\Gamma_s^{\text{Exp}} = (0.091 \pm 0.008)\,\text{ps}^{-1}$$

$$\Delta\Gamma_d^{\text{SM}} = (0.0029 \pm 0.0007)\,\text{ps}^{-1}$$
$$\Delta\Gamma_d^{\text{Exp}} = (0.0059 \pm 0.0079)\,\text{ps}^{-1}$$

$\Rightarrow$ need preciser measurement of $\Delta\Gamma_d$

Contours of $\Delta(\log L) = 0.5$



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Error budget $\Delta\Gamma_s$

[Lenz/Nierste arXiv:1102.4274]

- 1× decay constant f_{B_q} — $\delta(f_{B_s}) \sim 13.2\%$

  2× dim-6 matrix elements: B_{B_q}, $\tilde{B}_S^q$ — $\delta(B_{B_s}, \tilde{B}_S^s) \sim 4.8\%$

  ⇒ improved Lattice results already available
- dim-7 matrix elements: $R_{0,1,2,3}$ and $\widetilde{R}_{0,1,2,3}$ — $\delta(\widetilde{R}_2) \sim 17.2\%$, $\delta(\widetilde{R}_0) \sim 3.4\%$

  ⇒ No lattice predictions yet, but QCD sum rules [Mannel/Pecjak/Pivovarov hep-ph/0703244]
- renormalisation scale μ_b — $\delta(\mu_b) \sim 7.8\%$
- CKM V_{cb} — $\delta(\mu_b) \sim 3.4\%$

⇒ total $\delta(\Delta\Gamma_s) \sim 25\%$

Theoretical predictions of Γ_{12}^q

Based on Heavy Quark Expansion (HQE) = local OPE, used also for $\Delta B = 0$

$\lambda = \Lambda_{\mathrm{QCD}}/m_b$

$$\Gamma_{12}^q = \lambda^3\left(\Gamma_3^{(0)} + \frac{\alpha_s}{4\pi}\Gamma_3^{(1)}\right) + \lambda^4\left(\Gamma_4^{(0)} + \ldots\right) + \lambda^5\left(\Gamma_5^{(0)} + \ldots\right) + \ldots$$

[Beneke/Buchalla hep-ph/9605259; Beneke/Buchalla/Greub/Lenz/Nierste 9808385; Beneke/Buchalla/Lenz/Nierste 0307344; Ciuchini/Franco/Lubicz/Mescia/Tarantino 0308029; Lenz/Nierste 0612167; Badin/Gabiani/Petrov arXiv:0707.0294]

- individual contributions show convergent behaviour
- HQE works well for lifetimes ($\Delta B = 0$) . . . assuming no NP

Overall SM compares well to data

$$\left(\frac{\Delta\Gamma_s}{\Delta M_s}\right)^{\mathrm{Exp}} \Big/ \left(\frac{\Delta\Gamma_s}{\Delta M_s}\right)^{\mathrm{SM}} = 1.02 \pm 0.09 \pm 0.19$$

Dominant uncertainty from NNLO QCD and Lattice

Theoretical predictions of $a_{\rm fs}^q$

[Lenz/Nierste arXiv:1102.4274]

Highly sensitive to CKM input of V_{ub}, V_{cb} and γ (of which errors not included)

$$a_{\rm fs}^d = -(4.1 \pm 0.6) \cdot 10^{-4}, \qquad a_{\rm fs}^s = (1.9 \pm 0.3) \cdot 10^{-5},$$

$$\zeta_d = -(4.3 \pm 1.4)^\circ, \qquad \zeta_s = (0.22 \pm 0.06)^\circ,$$

Experimental results

$a_{\rm fs}^d = (68 \pm 45 \pm 14) \cdot 10^{-4}$ [DØ 1208.5813]

$a_{\rm fs}^s = -(1120 \pm 740 \pm 170) \cdot 10^{-5}$ [DØ 1207.1769]

$a_{\rm fs}^d = (6 \pm 17^{+38}_{-32}) \cdot 10^{-4}$ [BaBar 1305.1575]

$a_{\rm fs}^s = -(60 \pm 500 \pm 360) \cdot 10^{-5}$ [LHCb 1308.1048]

Prospects for LHCb 3 fb^{-1}: $\sigma(a_{\rm fs}^d) \sim 36 \cdot 10^{-4}$, [talk K. Kreplin at Beauty 2014]

$\sigma(a_{\rm fs}^s) \sim (200 - 300) \cdot 10^{-5}$

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Like-sign dimuon asymmetry

[Lenz/Nierste arXiv:1102.4274]

$$A_{\rm sl}^b = 0.406\, a_{\rm fs}^d + 0.594\, a_{\rm fs}^s = -(2.3 \pm 0.4) \cdot 10^{-4}$$

Experimental result from DØ assuming $\Delta\Gamma_d/\Gamma_d$ = SM [DØ arXiv:1310.0447]

$$A_{\rm sl}^b = -(49.6 \pm 15.3 \pm 7.2) \cdot 10^{-4}$$

$\Rightarrow$ 2.8σ from theory

Beyond the Standard Model

New physics in M_{12}^q

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

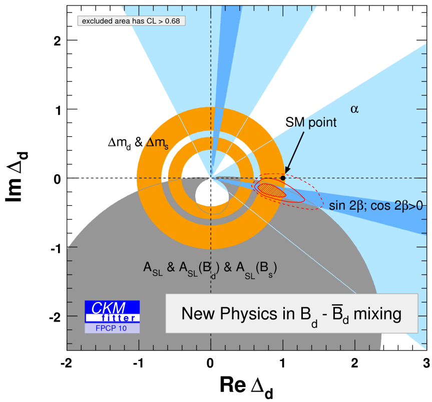
$$M_{12}^q = M_{12}^{\mathrm{SM},q} \cdot \Delta_q, \qquad \Delta_q = |\Delta_q| e^{i\phi_q^\Delta}, \qquad q = d, s$$

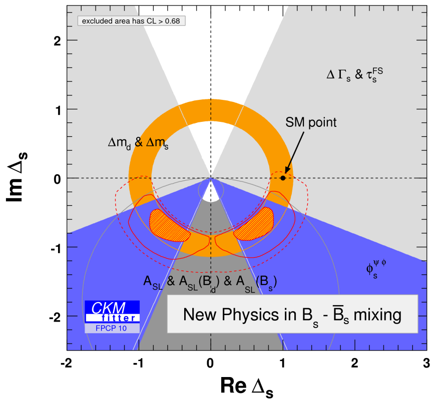
- 2 complex NP parameters → 4 dimensional NP parameter space
- B_d- and B_s-sector connected via A_{sl}^b

New physics in M_{12}^q

year 2010

[Lenz/Nierste/CKMfitter arXiv:1008.1593]

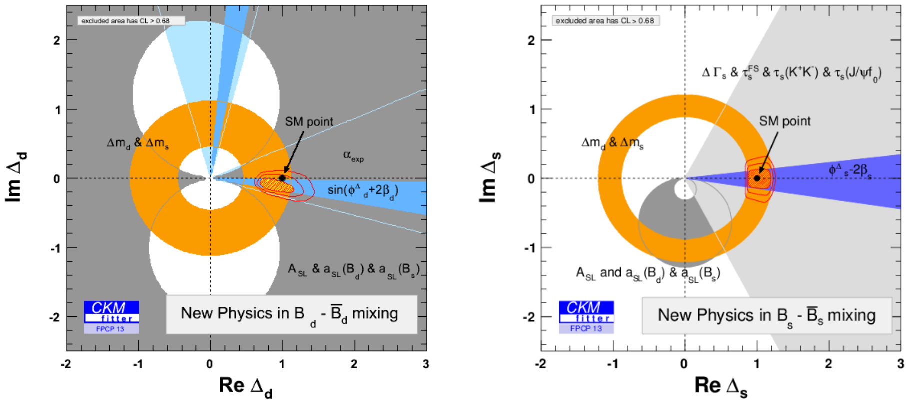




significance of SM $\qquad \Delta_d = 1$ (2D) $\rightarrow p = 2.5\sigma \qquad \Delta_s = 1$ (2D) $\rightarrow p = 2.7\sigma$

New physics in M_{12}^q

year 2010 ⟶ year 2013 [Lenz/Nierste/CKMfitter 1203.0238v2 and update FPCP 2013]



significance of SM $\Delta_d = 1$ (2D) $\to p = 1.5\sigma$ $\Delta_s = 1$ (2D) $\to p = 0.0\sigma$

$A_{\rm sl}^b$ and $Br(B \to \tau\nu_\tau)$ prefer $\phi_d^\Delta < 0$:

$\Rightarrow$ SM-hypothesis $\Delta_d = \Delta_s = 1$ (4D) has significance 1σ (compared to 3.6σ in 2010)

$\Rightarrow$ pull of $A_{\rm sl}^b$ is 3.4σ

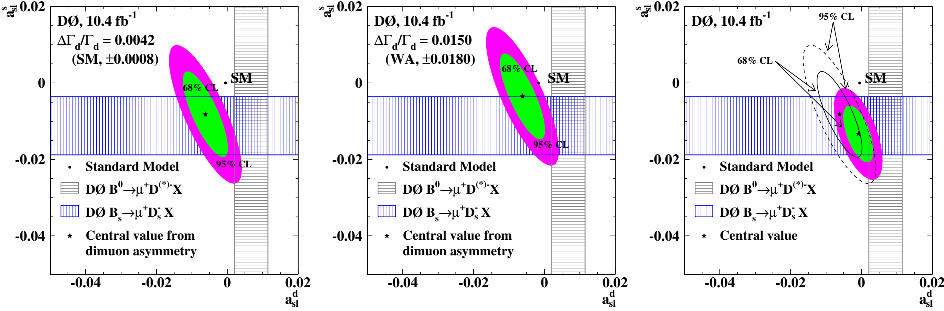
Status of $A^b_{\rm sl}$

Final analysis of DØ 10.4 fb^{-1} [DØ arXiv:1310.0447]

- complex analysis of $A_{\rm CP}$ and $a_{\rm CP}$ in several bins of μ-impact pmr. (IP)
- allows for combined fit of $a^d_{\rm fs}$, $a^s_{\rm fs}$ and $\Delta\Gamma_d$

$$a^d_{\rm fs} = (0.62 \pm 0.43)\%, \quad a^s_{\rm fs} = (-0.82 \pm 0.99)\%, \quad \Delta\Gamma_d/\Gamma_d = (0.50 \pm 1.38)\%$$

$\Rightarrow$ 3.0σ away from SM



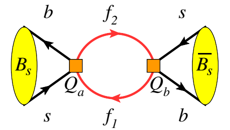
fixed $\Delta\Gamma_d/\Gamma_d$ = SM — fixed $\Delta\Gamma_d/\Gamma_d$ = world ave. — fitting also $\Delta\Gamma_d/\Gamma_d$

$\Rightarrow$ How well can we constrain NP to $\Gamma^d_{12} \longrightarrow \Delta\Gamma_d$ and $a^d_{\rm fs}$?

New physics in Γ_{12}^q ...

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

$$\Gamma_{12}^q = \Gamma_{12}^{q,\mathrm{SM}} + C_a C_b^* \times \mathrm{Im}\Big[\quad \Big]$$



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

- $\Delta\Gamma_s$ dominated by $b \to s\,c\bar{c}$
- $\Delta\Gamma_d$ also sizeable contributions from $b \to d + (u\bar{u},\, c\bar{u})$ with partial cancellations
- comparing $Br(b \to s\,c\bar{c}) = (23.7 \pm 1.3)\%$ with $Br(b \to d\,c\bar{c}) = (1.31 \pm 0.07)\%$
  $\Rightarrow$ NP in $b \to s\,c\bar{c}$ more severely constrained than $b \to d\,c\bar{c}$ [Krinner/Lenz/Rauh arXiv:1305.5390
- $b \to s\,\tau\bar{\tau}$ change $\Delta\Gamma_s$ at most by 30% from SM
  [Dighe/Kundu/Nandi 0705.4547, Bauer/Dunn 1006.1629, CB/Haisch 1109.1826]

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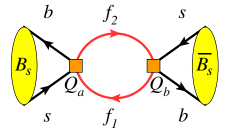

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⇒ Improve knowledge on NP in Γ_{12}^d to progress with A_{sl}^b:

- improve current bounds on $\Delta\Gamma_d = (0.006 \pm 0.008)\,\mathrm{ps}^{-1}$
- improve current bounds on a_{fs}^d

blue = $B \to X_d\gamma$, green a_{sl}^d, red = dim-8 $\sin 2\beta$

New physics in $\Delta\Gamma_d$

[CB/Haisch/Lenz/Pecjak/Tetlamatzi-Xolocotzi arXiv:1404.2531]

Model-independently, $\Delta B = 1$ dim-6 operators:

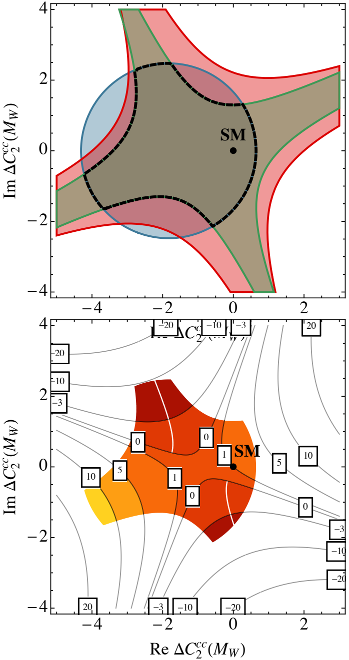
$$b \to d + (u\bar{u},\ c\bar{u},\ c\bar{c})$$

$$H_{\text{eff}} = \frac{4G_F}{\sqrt{2}} \sum_{p,p'=u,c} V_{pd}^* V_{p'b} \sum_{i=1,2} C_i^{pp'} O_i^{pp'}$$

$$O_1^{pp'} = (\bar{d}^\alpha \gamma^\mu P_L p^\beta)(\bar{p}'^\beta \gamma_\mu P_L b^\alpha)$$
$$O_2^{pp'} = (\bar{d} \gamma^\mu P_L p)(\bar{p}' \gamma_\mu P_L b)$$

$$\Rightarrow C_i^{pp'} = C_i^{\text{SM}} + \Delta C_i^{pp'}$$

- used experimental constraints from $B \to \pi\pi,\ \rho\pi,\ \rho\rho,\ D^*\pi,\ X_d\gamma$ and $\sin 2\beta$
- $\Delta\Gamma_d / \Delta\Gamma_d^{\text{SM}} \in [-1.0, 1.4]$ for $b \to d + (u\bar{u},\ c\bar{u})$
- huge effects of several 100% in $b \to d\, c\bar{c}$ can not be ruled out



New physics in $\Delta\Gamma_d$

[CB/Haisch/Lenz/Pecjak/Tetlamatzi-Xolocotzi arXiv:1404.2531]

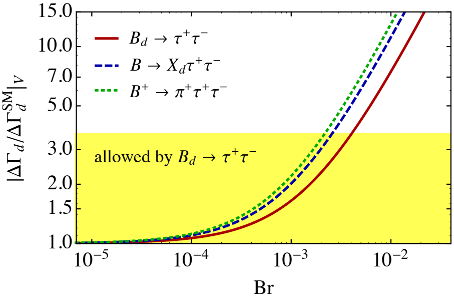
$$H_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} \sum_{i,j} C_{i,j} Q_{i,j}$$

Model-independently, $\Delta B = 1$ dim-6 operators:

$b \to d\,\tau\bar{\tau}$

$$Q_{S,AB} = \left(\bar{d} P_A b\right)\left(\bar{\tau} P_B \tau\right)$$
$$Q_{V,AB} = \left(\bar{d}\gamma^\mu P_A b\right)\left(\bar{\tau}\gamma_\mu P_B \tau\right)$$
$$Q_{T,A} = \left(\bar{d}\sigma^{\mu\nu} P_A b\right)\left(\bar{\tau}\sigma_{\mu\nu} P_A \tau\right)$$

- direct constraints from $Br(B_d \to \bar{\tau}\tau)$
- indirect (operator mixing) constraints from $Br(B \to X_d\gamma)$, $Br(B^+ \to \pi^+\bar{\tau}\tau)$
- large effects of 270% in $C_{V,AB}$
  smaller effects of 60% in $C_{S,AB}$
  can not be ruled out



Summary

Conclusion

- Theoretical methods (OPE, HQE) work well
  ($\Delta B = 0$: lifetimes and ratios of lifetimes ⇒ should also for $\Delta B = 2$: $\Delta\Gamma_q$ and $a_{\rm fs}^q$)

- SM and CKM picture describe data (ΔM_q, $\Delta\Gamma_q$)
  ⇒ soon improved lattice results of f_{B_q} and bag factors
  from several lattice groups
  ??? however, lacking results for dim-7 operators, needed for $\Delta\Gamma_q$

- huge NP effects not seen, current data still permits sizeable effects
  ⇒ except no satisfactory explanation of DØ measurement of
  like-sign dimuon asymmetry
  ??? NP in Γ_{12}^d

- better measurements needed for $a_{\rm fs}^s$, $a_{\rm fs}^d$ and $\Delta\Gamma_d$
  ⇒ LHCb and Belle II