Charming new physics in rare B decays and mixing

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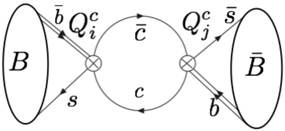
Outline

- Motivation
- Methodology
- Results
- Conclusions

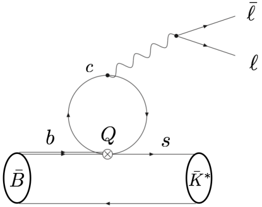
Central idea

B_s meson mixing, lifetimes and rare B decays all receive contributions from charmed 4 quark operators at 1-loop



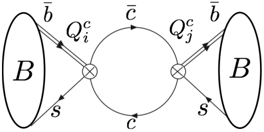
B_s-B_d Lifetime ratio

$$r = \left(\frac{\tau_{B_s}}{\tau_{B_d}}\right)$$



Width difference

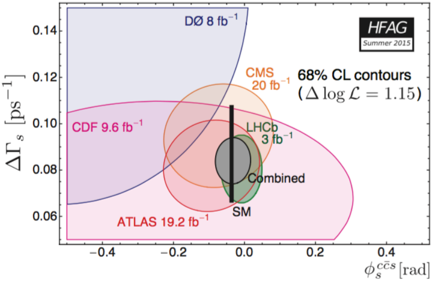
$$\Delta\Gamma_s$$



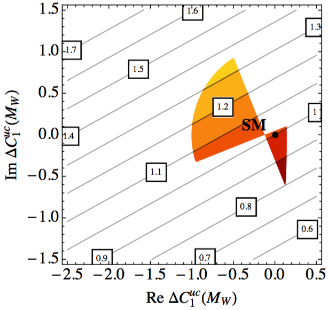
Rare B decay observables

$$A_{FB}, P_5'$$

Motivation: Mixing observables



http://www.slac.stanford.edu/xorg/hfag/osc/spring_2016

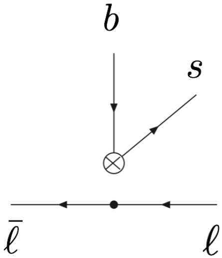


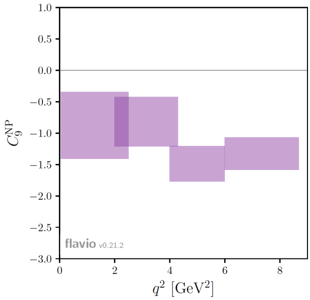
Bobeth,Haisch,Pecjack,Tetlalmatzi-Xolocotzi, 1404.2531

- Mixing observables such as the decay rate difference and semileptonic asymmetry show consistency with the SM
- Another important observable to consider the B_s-B_d lifetime ratio

If sizable NP contributions to $b \to c\bar{c}s$ couplings are present in mixing, they could also effect and constrain $b \to s\ell\bar{\ell}$

Motivation: Rare decay anomalies





$$Q_9^l = \frac{\alpha}{4\pi}(\bar{s}\gamma^\mu P_L b)(\bar{\ell}\gamma_\mu \ell)$$

Altmannshofer, Niehoff, Stangl, Straub, 1703.09189, and others

- Recent analysis of LHCb data suggests a negative contribution to the Wilson coefficient C_9
- Possible explanation for tensions in rare decays such as $B \to K^* \mu\mu$

Assume a negative shift to C_9 - Ask if there are viable charming BSM scenarios which reproduce this effect?

Operator Basis

Effective Hamiltonian

$$\mathcal{H}_{eff}^{c\bar{c}} = \frac{4G_F}{\sqrt{2}} V_{cb} V_{cs}^* \left[\Sigma_{i=1}^{10} \left(C_i^c Q_i^c + C_i^{c\prime} Q_i^{c\prime} \right) + h.c \right]$$

SM

$$Q_1^c = (\bar{c}_L^i \gamma_\mu b_L^j)(\bar{s}_L^j \gamma^\mu c_L^i), \qquad Q_2^c = (\bar{c}_L^i \gamma_\mu b_L^i)(\bar{s}_L^j \gamma^\mu c_L^j),$$

BSM

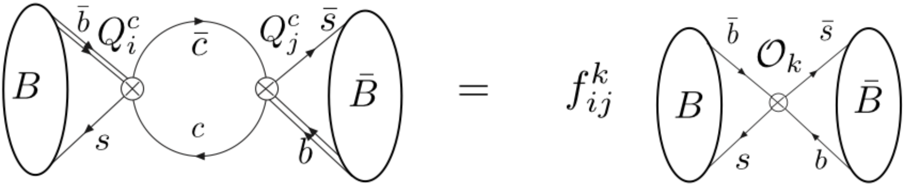
$$Q_3^c = (\bar{c}_R^i b_L^j)(\bar{s}_L^j c_R^i), \qquad Q_4^c = (\bar{c}_R^i b_L^i)(\bar{s}_L^j c_R^j),$$

$$Q_5^c = (\bar{c}_R^i \gamma_\mu b_R^j)(\bar{s}_L^j \gamma^\mu c_L^i), \qquad Q_6^c = (\bar{c}_R^i \gamma_\mu b_R^i)(\bar{s}_L^j \gamma^\mu c_L^j),$$

$$Q_7^c = (\bar{c}_L^i b_R^j)(\bar{s}_L^j c_R^i), \qquad Q_8^c = (\bar{c}_L^i b_R^i)(\bar{s}_L^j c_R^j),$$

$$Q_9^c = (\bar{c}_L^i \sigma_{\mu\nu} b_R^j)(\bar{s}_L^j \sigma^{\mu\nu} c_R^i), \qquad Q_{10}^c = (\bar{c}_L^i \sigma_{\mu\nu} b_R^i)(\bar{s}_L^j \sigma^{\mu\nu} c_R^j),$$

B_s-$\bar{B}_s$ mixing: Γ_{12}^{cc}



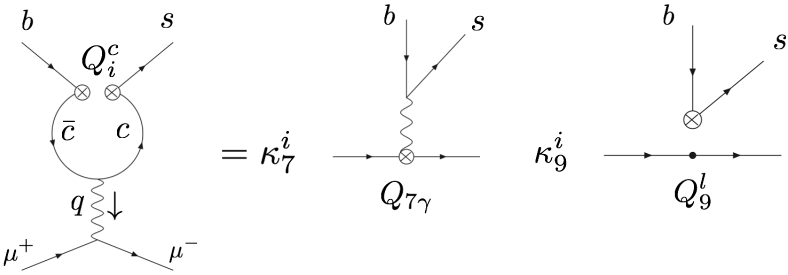
- Heavy Quark Expansion reduces original $\Delta B = 1$ basis to standard $\Delta B = 2$ basis

$$\Gamma_{12}^{cc} \sim \Sigma_{ijk} C_i^c C_j^c f_{ij}^k \frac{\langle B_s^0 | \mathcal{O}_k | \bar{B}_s^0 \rangle}{2M_B}$$

Width difference

$$\Delta\Gamma_s = 2|\Gamma_{12}| \cos \phi_{12}^s$$

Rare Decay: Short distance effects



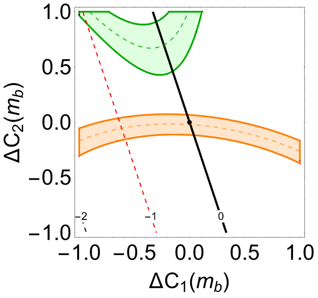
$$\Delta C_9^{eff}(q^2) = \sum_{i=1}^{10} C_i \kappa_9^i$$

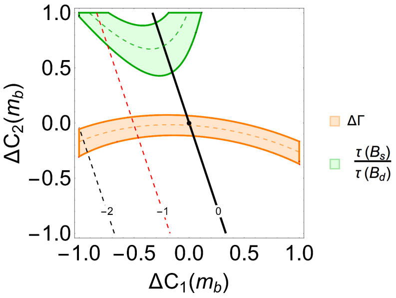
$$\Delta C_7^{eff}(q^2) = \sum_{i=1}^{10} C_i \kappa_7^i$$

$$\Delta C_{\text{eff}}^9 = \left[\left((3\Delta C_1 + \Delta C_2) - \tfrac{1}{2}(3\Delta C_3 + \Delta C_4) \right) h(q^2) - \tfrac{2}{9}(3\Delta C_3 + \Delta C_4) \right]$$

- $h(q^2)$ is a loop function

Results I: Low Scale Constraints on $\Delta C^9_{eff}(q^2)$





$$\Delta C^9_{eff}(q^2 = 2GeV^2)$$

$$\Delta C^9_{eff}(q^2 = 5GeV^2)$$

- q^2 dependence of ΔC^9_{eff} is more sensitive to NP at higher values of q^2
- Negative shift of $\Delta C^9_{eff} = -1$ can be accommodated by $\Delta\Gamma_s$

Renormalization Group Evolution

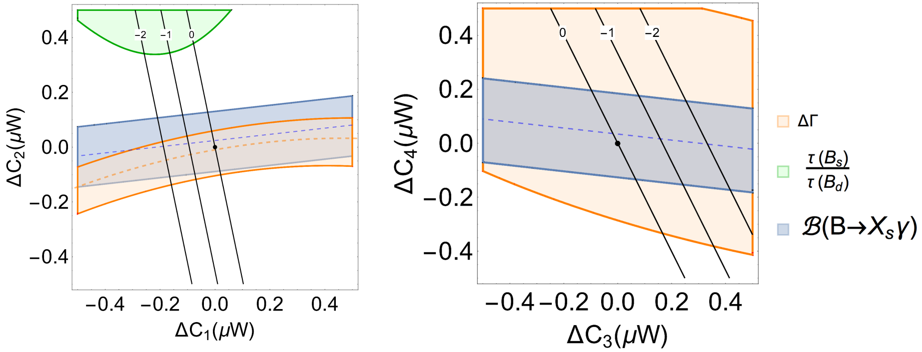
- When NP enters at the high scale $\mu \approx M_W$ Renormalization Group effects become important

$$\Delta C^7_{eff}(\mu_b) = 0.02 C^c_1(M_W) - 0.19 C^c_2(M_W) - 0.01 C^c_3(M_W) - 0.13 C^c_4(M_W)$$

$$\Delta C^9_{eff}(\mu_b) = 8.65 C^c_1(M_W) + 2.00 C^c_2(M_W) - 4.33 C^c_3(M_W) - 1.95 C^c_4(M_W)$$

- ΔC^7_{eff} generates $B \to X_s \gamma$ constraint
- $C^c_3(M_W)$ and $C^c_4(M_W)$ are new in ΔC^7_{eff} and only appear at 2-loop

Results II: High Scale Constraints on $\Delta C^9_{eff}(5GeV^2)$

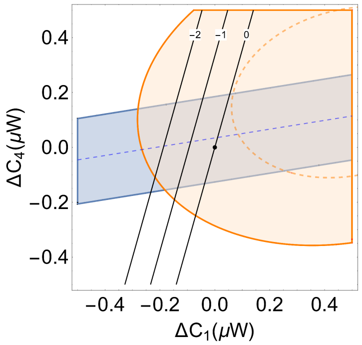


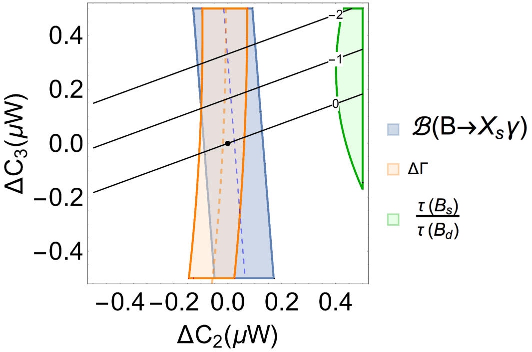
NP in C_1-C_2 scenario

NP in C_3-C_4 scenario

- In the C_1-C_4 and C_3-C_4 scenario, $B \to X_s\gamma$ and mixing constraints allows a negative shift to C_9^{eff}

Results III: Constraints on $\Delta C^9_{eff}(5GeV^2)$





NP in C_1-C_4 scenario

NP in C_2-C_3 scenario

- Lifetime ratio $r = \left(\frac{\tau_{B_s}}{\tau_{B_d}}\right)$ could discriminate between different scenarios - all 6 combinations of Wilson coefficients under investigation

$B_s - B_d$ Lifetime Ratio - Outlook

- New Dirac structures emerge in $\Delta B = 0$ operator basis $\Rightarrow$ New matrix elements

$$\mathcal{O}^s_{V-A} = (\bar{b}_L \gamma^\mu s_L)(\bar{s}_L \gamma_\mu b_L)$$
$$\mathcal{O}^s_{S-P} = (\bar{b}_R s_L)(\bar{s}_L b_R)$$
$$T^s_{V-A} = (\bar{b}_L \gamma^\mu T^a s_L)(\bar{s}_L \gamma_\mu T^a b_L)$$
$$T^s_{S-P} = (\bar{b}_R T^a s_L)(\bar{s}_L T^a b_R)$$

M.Neubert and C.Sachrajda, hep-ph/9709386

New Operators

$$\mathcal{O}^s_{LR} = (\bar{b}_L \gamma^\mu s_L)(\bar{s}_R \gamma_\mu b_R)$$
$$\mathcal{O}^S_{LL} = (\bar{b}_R s_L)(\bar{s}_R b_L)$$
$$T^s_{LR} = (\bar{b}_L \gamma^\mu T^a s_L)(\bar{s}_R \gamma_\mu T^a b_R)$$
$$T^S_{LL} = (\bar{b}_R T^a s_L)(\bar{s}_R T^a b_L)$$

- In Heavy Quark Limit Number of independent operators has been reduced
- Eliminate odd parity operator matrix elements$\rightarrow$ Reduce number more
- Large N_c limit $\rightarrow$ Some matrix new elements may be suppressed

Conclusions

- Deviations of SM theory predictions from experimental data could be explained by a negative shift in C_9
- Charmed new physics in $b \to c\bar{c}s$ transitions could provide an explanation, but will affect mixing
- A feature of the low scale scenario where NP enters at $\mu \approx 4.6$ is the q^2 dependence of ΔC_9^{eff}
- Bounds from mixing observables $\frac{\Delta\Gamma}{\Delta M}$ and from inclusive $\mathcal{B}r(B \to X_s\gamma)$ allow a negative shift to C_9 in NP high scales BSM scenarios for both SM and BSM Wilson coefficients
- Lifetime ratio $r = \left(\frac{\tau_{B_s}}{\tau_{B_d}}\right)$ may be able to discriminate between different scenarios - currently under investigation
- New $\Delta B = 0$ operators appear in Lifetime calculation - can be reduced in HQ limit

Back up slides

$\Delta C_7(q^2)$ and Loop functions

- The coefficients ΔC_9 and ΔC_7 are

$$\Delta C_{\text{eff}}^7 = \frac{m_c}{m_b}\left[(4(3C_9 + C_{10}) - (3C_7 + C_8))\, y + \frac{(4(3C_5+C_6)-(3C_7+C_8))}{6}\right]$$

$$\Delta C_{\text{eff}}^9 = \left[\left((3C_1 + C_2) - \frac{1}{2}(3C_3 + C_4)\right) h - \frac{2}{9}(3C_3 + C_4)\right]$$

- The loop functions are

$$h(q^2, m_c, \mu) = -\frac{4}{9}\left(\ln\left(\frac{m_c^2}{\mu^2}\right) - \frac{2}{3} - z + (z+2)\sqrt{|z-1|}\arctan\left(\frac{1}{\sqrt{z-1}}\right)\right)$$

$$y(q^2, m_c, \mu) = -\frac{1}{3}\left(\ln\left(\frac{m_c^2}{\mu^2}\right) - \frac{3}{2} + 2\sqrt{|z-1|}\arctan\left(\frac{1}{\sqrt{z-1}}\right)\right)$$

- $z = \frac{4m_c^2}{q^2}$, $z < 1$