Explaining the $b \to s$ anomalies at one-loop

Rupert Coy

Laboratoire Charles Coulomb (L2C), CNRS-Université de Montpellier

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Outline

1. What are R_K and R_{K^*}?
2. Review of Effective Field Theory
3. Tree-level explanations
4. One-loop explanations

What are R_K and R_{K^*}?

- SM predictions:

$$R_K[1,6] = 1.00 \pm 0.01$$
$$R_{K^*}[1.1,6] = 1.00 \pm 0.01$$
$$R_{K^*}[0.045,1.1] \simeq 0.92 \pm 0.03$$
$$BR(B_s \to \mu^+\mu^-) = (3.65 \pm 0.23) \times 10^{-9}$$

- LHCb results:

$$R_K[1,6] = 0.846^{+0.062}_{-0.056} \qquad (2.5\sigma)$$
$$R_{K^*}[1.1,6] = 0.660^{+0.113}_{-0.074} \qquad (3.0\sigma)$$
$$R_{K^*}[0.045,1.1] = 0.685^{+0.122}_{-0.083} \qquad (1.9\sigma)$$
$$BR(B_s \to \mu^+\mu^-) = (2.93 \pm 0.41) \times 10^{-9} \qquad (1.5\sigma)$$

Effective Field Theory

- See blackboard :)

Tree-level explanations of the anomalies

- In Weak Effective Theory (WET), defined below the EW scale, have

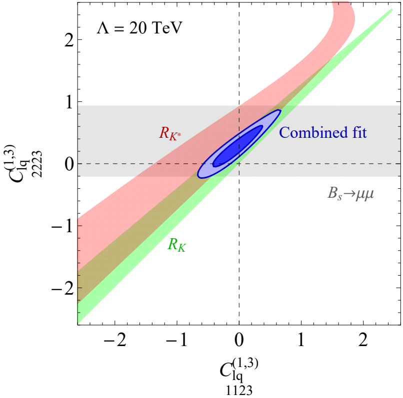
$$\mathcal{O}_9 = (\bar{s}\gamma_\mu P_L b)(\ell\gamma^\mu\ell) \quad \mathcal{O}_{10} = (\bar{s}\gamma_\mu P_L b)(\ell\gamma^\mu\gamma_5\ell) \tag{1}$$

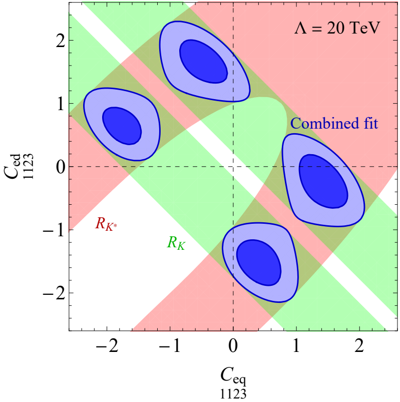
$$\mathcal{O}_9' = (\bar{s}\gamma_\mu P_R b)(\ell\gamma^\mu\ell) \quad \mathcal{O}_{10}' = (\bar{s}\gamma_\mu P_R b)(\ell\gamma^\mu\gamma_5\ell)\ , \tag{2}$$

with the Lagrangian normalised by

$$\mathcal{L}_{WET} = \frac{e^2 V_{tb} V_{ts}^*}{8\pi^2 v^2} \sum C_i \mathcal{O}_i + h.c. \tag{3}$$

Tree-level explanations of the anomalies





One-loop explanations of the anomalies

- Bounds from LFU of meson decays: define

$$r_K^{e/\mu} = \frac{BR(K^- \to e\overline{\nu})}{BR(K^- \to \mu\overline{\nu})} \quad (4)$$

$$r_D^{\mu/e} = \frac{BR(B \to D\mu\overline{\nu})}{BR(B \to De\overline{\nu})} \quad (5)$$

Then $C_{lq}^{(3)}$ is very constrained by the measurements

$$r_K^{e/\mu(exp)} = (2.488 \pm 0.010) \times 10^{-5} \quad r_D^{\mu/e(exp)} = 0.995 \pm 0.045 \quad (6)$$

$$r_K^{e/\mu(SM)} = (2.477 \pm 0.001) \times 10^{-5} \quad r_D^{\mu/e(SM)} = 0.9957 \pm 0.0004 \quad (7)$$

Results

Wilson Coeff.	Indices	2σ range	R_K
$C_{lq}^{(3)}$	(2222)	$(-0.03, 0.10)$	≈ 1
	(2233)	$(-0.60, 0.24)$	$(0.95, 1.13)$
$C_{lq}^{(1)}$	(2222)	$(-5.4, 0.90)$	$(0.48, 1.1)$
	(2233)	$(-0.31, 0.72)$	$(0.85, 1.07)$
$C_{lq}^{(1)} = C_{lq}^{(3)}$	(2222)	$(-0.03, 0.10)$	$(0.99, 1.03)$
	(2233)	$(-0.56, 0.42)$	$(0.83, 1.25)$
C_{eq}	(2222)	$(-1.92, 10)$	≈ 1
	(2233)	$(-0.90, 0.24)$	≈ 1
C_{lu}	(2223)	$(-10, 10)$	$(0.88, 1.07)$
	(2233)	$(-0.76, 0.36)$	$(0.92, 1.04)$
C_{eu}	(2223)	$(-10, 2.4)$	$(1, 1.07)$
	(2233)	$(-0.28, 0.96)$	≈ 1
C_{He}, $C_{Hl}^{(1)}$ or $C_{Hl}^{(3)}$	(22)	$(-0.04, 0.05)$	≈ 1
$C_{Hl}^{(1)} = -C_{Hl}^{(3)}$	(22)	$(0.0, 0.13)$	≈ 1

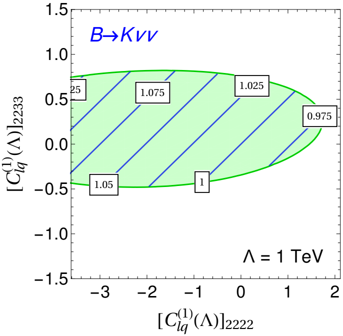
Results

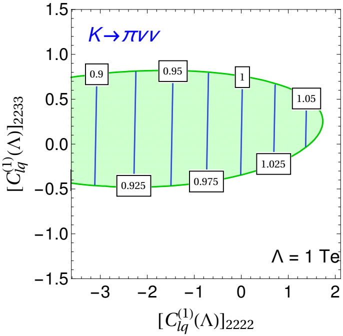
Wilson Coeff.	Indices	2σ range	R_K
$C_{lq}^{(3)}$	(1122)	$(-0.10, 0.02)$	≈ 1
	(1133)	$(-0.05, 0.48)$	$(0.98, 1.11)$
$C_{lq}^{(1)}$	(1122)	$(-0.19, 0.14)$	≈ 1
	(1133)	$(-0.41, 0.02)$	$(0.91, 1.01)$
$C_{lq}^{(1)} = C_{lq}^{(3)}$	(1122)	$(-0.10, 0.03)$	≈ 1
	(1133)	$(-0.41, 0.18)$	$(0.84, 1.09)$
C_{eq}	(1122)	$(-0.35, 0.83)$	≈ 1
	(1133)	$(-0.21, 0.28)$	≈ 1
C_{lu}	(1123)	$(-1.5, 1.5)$	$(0.97, 1.02)$
	(1133)	$(-0.02, 0.43)$	$(0.95, 1.01)$
C_{eu}	(1123)	$(-1.5, 1.5)$	≈ 1
	(1133)	$(-0.29, 0.21)$	≈ 1
C_{He}, $C_{Hl}^{(1)}$ or $C_{Hl}^{(3)}$	(11)	$(-0.02, 0.03)$	≈ 1
$C_{Hl}^{(1)} = -C_{Hl}^{(3)}$	(11)	$(-0.03, 0.02)$	≈ 1

Complementary signatures in EFT?

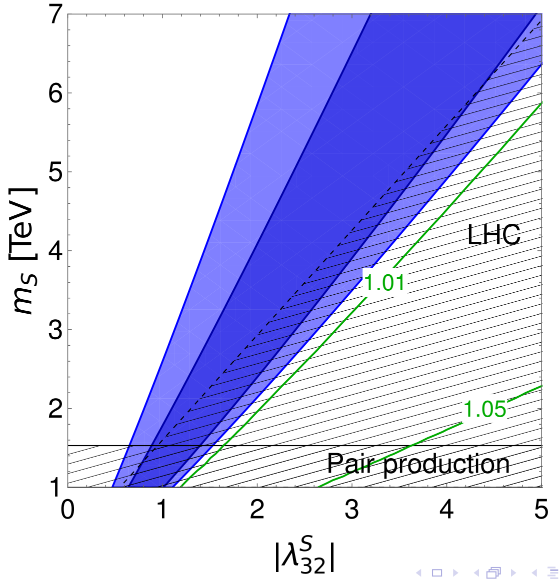
- Contribution to anomalous magnetic moment of muon is

$$\Delta a_\mu \simeq -\frac{32 m_\mu^2 y_t^2}{(16\pi^2)^2\Lambda^2}\left[\left(3C^{(3)}_{\substack{lq\\2233}} - C^{(1)}_{\substack{lq\\2233}}\right)|V_{tb}|^2 - C_{\substack{lu\\2233}}\right]$$
$$\times\left(\log\frac{m_t}{m_\mu} + \frac{15}{32}\log\frac{\Lambda}{m_t}\right)\log\frac{\Lambda}{m_t}\,. \qquad (8)$$





LQ with single coupling



LQ with single coupling