Role of Tensor operators in R_K and R_{K^*}

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Recent LHCb results

- Recent LHCb measurements

Observable	SM prediction		Measurement	
$R_{K^*}^{\text{low}}$	0.92 ± 0.02	[Capdevila et. al.]	$[0.58,\ 0.77]$	[Aaij et. al.]
$R_{K^*}^{\text{cen}}$	1.00 ± 0.01	[Bordone et. al.] [D-Genon et. al.]	$[0.60,\ 0.81]$	[Aaij et. al.]

- Definition of the observable

$$R_{K^*} \equiv \frac{\mathcal{B}(\bar{B}_d \longrightarrow \bar{K}^* \mu^+ \mu^-)}{\mathcal{B}(\bar{B}_d \longrightarrow \bar{K}^* e^+ e^-)}$$

- $q^2 (\equiv (p_{\ell^+} + p_{\ell^-})^2)$ bins: (a) Low bin $[0.045,\ 1.1]$, and (b) Central bin $[1.1,\ 6]$ GeV^2

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$R_K^{\rm cen}$	1.00 ± 0.01	[Bordone et. al.]	$[0.66,\ 0.84]$	[Aaij et. al.]

Some previous results: inclusive modes

$$\mathcal{B}^{\text{low}(\text{high})}_{X_s\ell\ell} \equiv \mathcal{B}(\bar{B}_d \longrightarrow X_s\ell^+\ell^-),\ q^2 \in [1,\ 6]\ ([14.2,\ 25])$$

Observable	SM prediction	Measurement
$\mathcal{B}^{\text{low}}_{X_s\mu\mu} \times 10^6$	1.59 ± 0.11 [Huber]	$[0,\ 1.53]$ [Lees]
$\mathcal{B}^{\text{high}}_{X_s\mu\mu} \times 10^6$	0.24 ± 0.07	$[0.31,\ 0.91]$
$\mathcal{B}^{\text{low}}_{X_see} \times 10^6$	1.64 ± 0.11	$[1.42,\ 2.47]$
$\mathcal{B}^{\text{high}}_{X_see} \times 10^6$	0.21 ± 0.07	$[0.38,\ 0.75]$

Effective Lagrangian

- At quark level, all the decays we are concerned about, proceed via $b \longrightarrow s$ flavor changing transitions. [Chetyrkin et. al., Bobeth et. al.]

$$\mathcal{L}_{\rm eff} = -\frac{4G_F}{\sqrt{2}}\,\frac{\alpha_{\rm em}}{4\pi}\,V_{tb}V_{ts}^{*}\left(C_1\mathcal{O}_1^c + C_2\mathcal{O}_2^c + \sum_{i=3}^{6} C_i\mathcal{O}_i + \sum_{i=7}^{10} C_i\mathcal{O}_i + \sum_{i=7,9,10} C_{i'}\mathcal{O}_{i'} + \sum_{i=S,P,S',P',T,T5} C_i\mathcal{O}_i\right)$$

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- Dimension 6 local operators

$$\begin{aligned}
\mathcal{O}_{7(7')} &= \frac{1}{e}m_b[\bar{s}\sigma_{\mu\nu}P_{R(L)}b]F^{\mu\nu} \\
\mathcal{O}_{9(9')} &= [\bar{s}\gamma_\mu P_{L(R)}b][\bar{\ell}\gamma^\mu\ell], \quad \mathcal{O}_{10(10')} = [\bar{s}\gamma_\mu P_{L(R)}b][\bar{\ell}\gamma^\mu\gamma_5\ell] \\
\mathcal{O}_{S(S')} &= [\bar{s}P_{R(L)}b]\,[\bar{\ell}\ell], \qquad \mathcal{O}_{P(P')} = [\bar{s}P_{R(L)}b][\bar{\ell}\gamma_5\ell] \\
\mathcal{O}_T &= [\bar{s}\sigma_{\mu\nu}b][\bar{\ell}\sigma^{\mu\nu}\ell], \qquad \mathcal{O}_{T5} = [\bar{s}\sigma_{\mu\nu}b][\bar{\ell}\sigma^{\mu\nu}\gamma_5\ell]
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- Photonic dipole operators $\mathcal{O}_{7(7')}$ have universal contributions modulo lepton mass effects and hence, can not provide an explanation of the R_K^* anomalies once bound from $B \longrightarrow X_s\gamma$ is taken into account [Descotes-Genon, Ghosh, Matias, Ramon].

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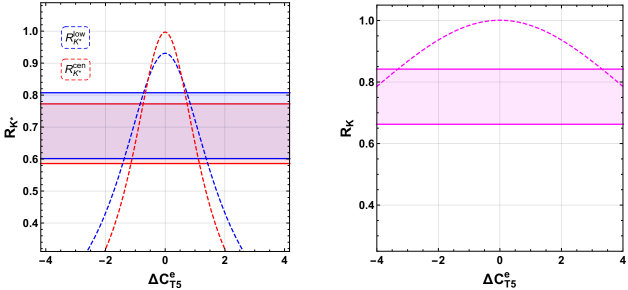
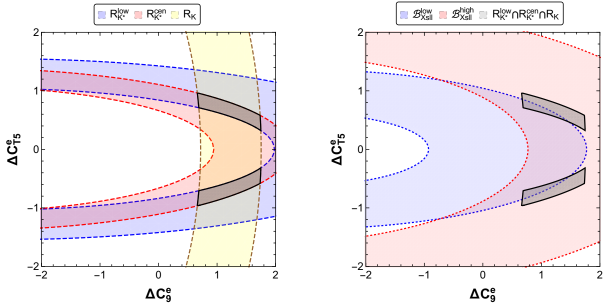
- For form-factors, we use [Bouchard] for $B \longrightarrow K$ matrix elements and [Straub] for the $B \longrightarrow K^*$ matrix elements.

Only Tensor operators



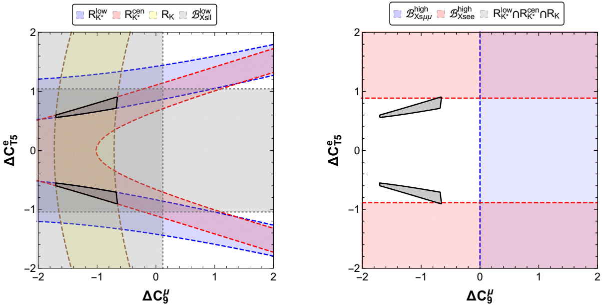
- Left panel: $\Delta C^e_{T5} \sim \pm 1$ explains $R_{K^*}^{cen}$ and $R_{K^*}^{low}$ simultaneously.
- Right panel: $\Delta C^e_{T5} \sim \pm 1$ can not reduce R_K^{cen}. It is far way from the allowed band. Hence a simultaneous explanation of R_K^{cen}, $R_{K^*}^{cen}$ and $R_{K^*}^{low}$ is not possible.
- All statements made here for ΔC^e_{T5} applies equally for ΔC^e_T.
- ΔC^μ_T: any non-zero value for them lead to $R_K > R_K^{SM}$ and $R_{K^*} > R_{K^*}^{SM}$ and thus, tensor operators in the muon sector are ruled out.

Combination of vectors and Tensors: ΔC_9^e - ΔC_{T5}^e plane



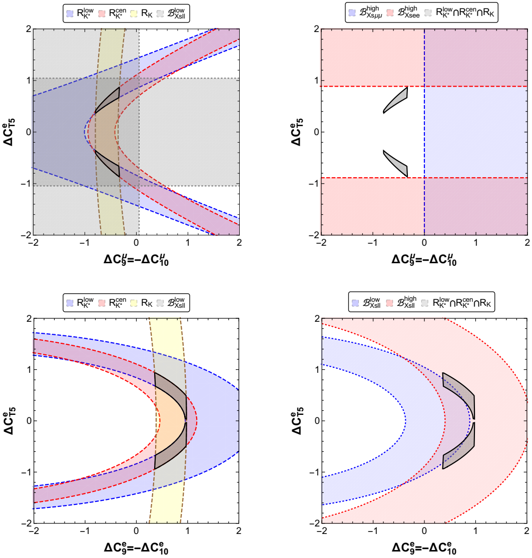
- The black shaded region is outside the $\Delta C_{T5}^e = 0$ line, and hence no simultaneous solutions are possible with only ΔC_9^e.
- The black shaded region in the right panel has a small overlap with blue and red regions.

Combination of vectors and Tensors: ΔC_9^{μ} - ΔC_{T5e}^{μ} plane



- Simultaneous explanation is in tension.

$\Delta C_9 = -\Delta C_{10}$ - ΔC^{μ}_{T5} planes



$SU(2) \times U(1)_Y$ gauge invariance

- Tensor operators do not get generated at the dimension-6 level.
- Some dimension-8 operators

$$1.\ \frac{C_{Y_d Y_\ell}}{\Lambda^4}[\bar{s}_R \sigma^{\mu\nu} Q_3 \tilde{H}][\bar{e}_{\ell R}\sigma_{\mu\nu} L_\ell \tilde{H}] \longrightarrow \frac{1}{2} C_{Y_d Y_\ell}\frac{v^2}{\Lambda^4}[\bar{s}_R \sigma^{\mu\nu} b_L][\bar{e}_{\ell R}\sigma_{\mu\nu} e_{\ell L}] = \frac{1}{4} C_{Y_d Y_\ell}\frac{v^2}{\Lambda^4}(\mathcal{O}_T - \mathcal{O}_{T5})$$

$$2.\ \frac{C_{sLeQ}}{\Lambda^4}[\bar{s}_R L_\ell \tilde{H}][\bar{e}_{\ell R} Q_3 \tilde{H}] \longrightarrow \frac{C_{sLeQ}}{\Lambda^4}\left(\frac{1}{2}[\bar{s}_R Q_3 \tilde{H}][\bar{e}_{\ell R} L_\ell \tilde{H}] + \frac{1}{8}[\bar{s}_R \sigma^{\mu\nu} Q_3 \tilde{H}][\bar{e}_{\ell R}\sigma_{\mu\nu} L_\ell \tilde{H}]\right)$$

$$= \frac{1}{8} C_{sLeQ}\frac{v^2}{\Lambda^4}\left(\mathcal{O}_{S'} - \mathcal{O}_{P'} + \frac{1}{4}\mathcal{O}_T - \frac{1}{4}\mathcal{O}_{T5}\right)$$

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$$2.\ \frac{C_{sLeQ}}{\Lambda^4}[\bar{s}_RL_\ell\tilde{H}][\bar{e}_{\ell R}Q_3\tilde{H}] \longrightarrow \frac{C_{sLeQ}}{\Lambda^4}\left(\frac{1}{2}[\bar{s}_RQ_3\tilde{H}][\bar{e}_{\ell R}L_\ell\tilde{H}]+\frac{1}{8}[\bar{s}_R\sigma^{\mu\nu}Q_3\tilde{H}][\bar{e}_{\ell R}\sigma_{\mu\nu}L_\ell\tilde{H}]\right)$$

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- The second operator is much easier to generate and common. However it satisfies

$$\Delta C^e_{S'} = -\Delta C^e_{P'} = 4\Delta C^e_{T5} = -4\Delta C^e_T\,.$$

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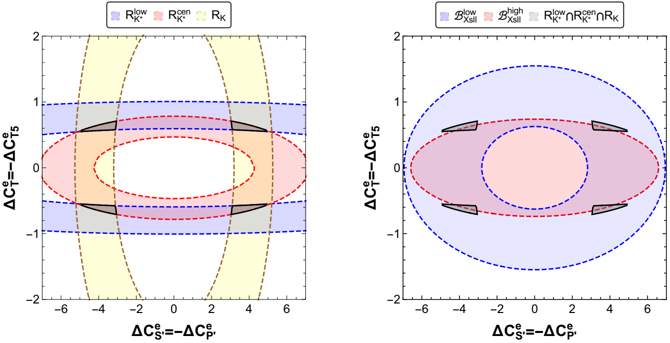

- $\Delta C_{S'}^e = -\Delta C_{P'}^e \approx 3 \Rightarrow \Lambda \sim (C_{sLeQ})^{1/4}\, 1.5$ TeV.
- Unfortunately, for such large values of $\Delta C_{S'}^e$, $\mathcal{B}_{ee}$ exceeds the experimental upper bound.

THANK YOU