Constraints on scalar and tensor Wilson coefficients

— all preliminary —

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Rare *B* decays in 2015 – experiment and theory

University of Edinburgh

Motivation

In Standard Model: $b \to s + \bar{\ell}\ell$ mediated by dipole and vectorial couplings

SM: $\mathcal{O}_7 \;\propto\; m_b[\bar{s}\,\sigma^{\mu\nu} P_R\, b]F_{\mu\nu}, \qquad \mathcal{O}_{9(10)} \;\propto\; [\bar{s}\,\gamma^{\mu} P_L\, b][\bar{\ell}\,\gamma_{\mu}(\gamma_5)\,\ell]$

whereas (pseudo-)scalar and tensorial couplings

S + P: $\mathcal{O}_{S(S')} \;\propto\; [\bar{s}\,P_{R(L)}\,b][\bar{\ell}\,\ell] \qquad \mathcal{O}_{P(P')} \;\propto\; [\bar{s}\,P_{R(L)}\,b][\bar{\ell}\,\gamma_5\,\ell]$

T + T5: $\mathcal{O}_{T} \;\propto\; [\bar{s}\,\sigma_{\mu\nu}\,b][\bar{\ell}\,\sigma^{\mu\nu}\,\ell] \qquad \mathcal{O}_{T5} \;\propto\; \frac{i}{2}\,\varepsilon^{\mu\nu\alpha\beta}[\bar{s}\,\sigma_{\mu\nu}\,b][\bar{\ell}\,\sigma_{\alpha\beta}\,\ell]$

kinematically suppressed in most observables

Well-known exception: helicity-suppression m_ℓ/m_b (or $m_\ell/\sqrt{q^2}$) of vectorial couplings in

$$Br(B_s \to \bar{\mu}\mu) \;\propto\; \left|C_S - C_{S'}\right|^2 + \left|(C_P - C_{P'}) + \frac{2m_\mu}{m_{B_s}}(C_{10} - C_{10'})\right|^2$$

$\Rightarrow$ allows to constrain also $(C_S - C_{S'})$ & $(C_P - C_{P'})$

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Yes !!! ⇒ Angular distributions of ...

$B \to K \bar{\ell}\ell$

$$\frac{1}{\Gamma}\frac{d^2\Gamma}{dq^2 d\cos\theta_\ell} = \frac{F_H(q^2)}{2} + A_{\rm FB}(q^2)\cos\theta_\ell + \frac{3}{4}\left[1 - F_H(q^2)\right]\sin^2\theta_\ell$$

Besides $d\Gamma/dq^2$, two more obs's measured [LHCb 3/fb arXiv:1403.8045]

In SM

- $F_H \propto m_\ell^2/q^2$ tiny for $\ell = e, \mu$ and $q^2 \gtrsim 1$ GeV^2
  + reduced FF uncertainties @ low- & high-q^2
  [CB/Hiller + (Piranishvili 0709.4174, van Dyk/Wacker 1111.2558, van Dyk 1212.2321)]
- $A_{\rm FB} \simeq 0 + \mathcal{O}(\alpha_e) + \mathcal{O}(\dim 8)$ up to “QED-bkg” & higher dim. m_b^2/m_W^2

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$B \to K^* \bar{\ell}\ell$

$$\frac{d^4\Gamma}{dq^2 d\cos\theta_\ell d\cos\theta_K d\phi} \propto \sum_{i=1s,\dots,9} J_i(q^2) f_i(\theta_\ell, \theta_K, \phi)$$

Some $J_i(q^2)$ measured, but assuming $C_{S,P,T} = 0$ & $m_\ell = 0$

In SM

- $(J_{1s} - 3J_{2s}) \propto m_\ell^2/q^2$
- $(J_{1c} + J_{2c}) \propto m_\ell^2/q^2$
- $J_{6c} \simeq 0 + \mathcal{O}(\alpha_e) + \mathcal{O}(\dim 8)$ ← contributes to $A_{\rm FB}$

Yes !!! ⇒ Angular distributions of . . .

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$$\frac{1}{\Gamma}\frac{d^2\Gamma}{dq^2 d\cos\theta_\ell} = \frac{F_H(q^2)}{2} + A_{FB}(q^2)\cos\theta_\ell + \frac{3}{4}\left[1 - F_H(q^2)\right]\sin^2\theta_\ell$$

Beyond SM
$m_\ell \to 0$

- $F_H \propto \left[\ldots(|C_T|^2 + |C_{T5}|^2) + \ldots(|C_S + C_{S'}|^2 + |C_P + C_{P'}|^2)\right]\big/\Gamma$
- $A_{FB} \propto \mathrm{Re}\left[(C_P + C_{P'})\,C_{T5}^* + (C_S + C_{S'})\,C_T^*\right]\big/\Gamma$

"…" denotes non-vanishing kinematic factors for $m_\ell \to 0$

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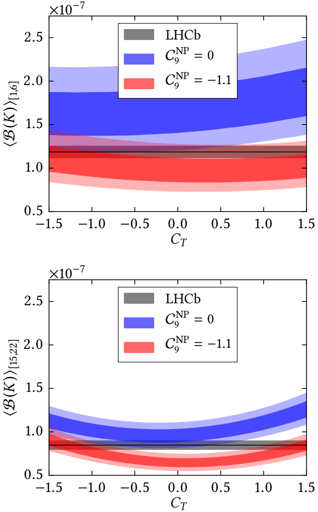
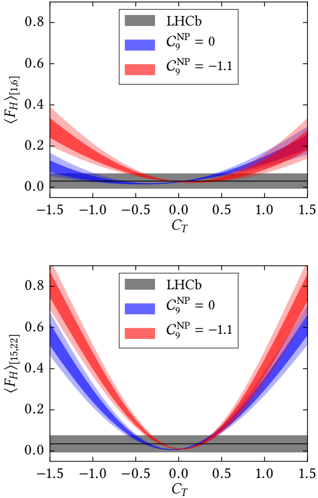
- $J_{6c} \propto \mathrm{Re}\left[(C_P - C_{P'})\,C_T^* - (C_S - C_{S'})\,C_{T5}^*\right]$

Example: sensitivities to tensorial C_T $\quad B \to K\bar{\ell}\ell$

Br :



F_H :

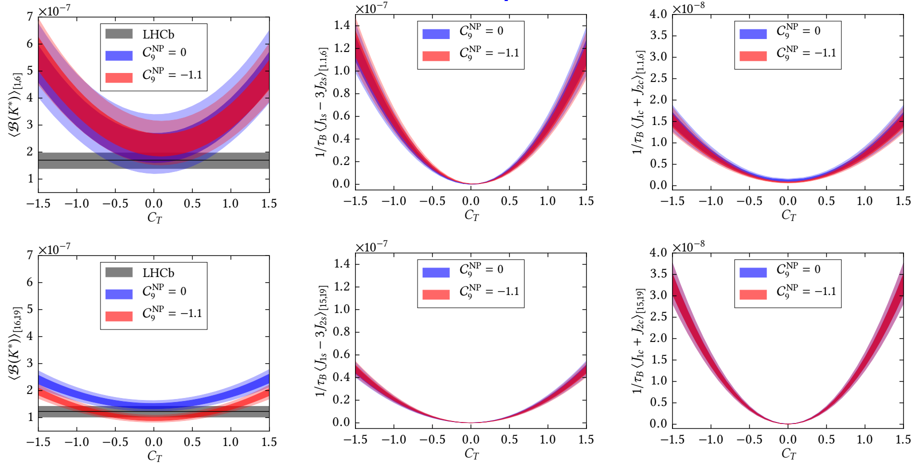


blue ($C_9^{NP} = 0$)/red ($C_9^{NP} = -1.1$) theory uncertainties: form factors, sub-leading $1/m_b$, CKM, . . .

grey bands = 1 σ measurement from LHCb:

- $B \to K\bar{\ell}\ell$ (3/fb) a) *Br* and b) $F_H + A_{FB}$ [a) arXiv:1403.8044, b) 1403.8045]
- $B \to K^*\bar{\ell}\ell$ (1/fb) *Br* only [arXiv:1304.6325]

Example: sensitivities to tensorial C_T — $B \to K^* \bar{\ell}\ell$



Br $(J_{1s} - 3J_{2s})$ $(J_{1c} + J_{2c})$

blue ($C_9^{NP} = 0$)/red ($C_9^{NP} = -1.1$) theory uncertainties: form factors, sub-leading $1/m_b$, CKM, ...

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⇒ Global fit of S + P and T + T5 exploiting "helicity-suppression" of vectorial cpl's in

$$Br(B_s \to \bar{\mu}\mu) \text{ and } F_H, A_{\rm FB} \text{ in } B \to K\bar{\ell}\ell$$

compared to suppression of S + P and T + T5 cpl's in other observables

$\Rightarrow$ Global fit of S + P and T + T5 exploiting "helicity-suppression" of vectorial cpl's in

$Br(B_s \to \bar{\mu}\mu)$ and $F_H, A_{\rm FB}$ in $B \to K\bar{\ell}\ell$

compared to suppression of S + P and T + T5 cpl's in other observables

Available data — use only $\ell = \mu$

. . . that does not assume $C_{S,P,T} = 0$ and $m_\ell = 0$

Channel	Observable	Kinematics	Source
$B_s \to \bar{\mu}\mu$	$\int d\tau Br(\tau)$	–	CMS + LHCb 1411.4413
$B^+ \to K^+\bar{\mu}\mu$	Br	$q^2 \in [1, 6], [14.18, 16], [> 16]$ GeV^2	CDF Public note 10894
		$q^2 \in [1.1, 6.0], [15.0, 22.0]$ GeV^2	LHCb 1403.8044
	$A_{\rm FB}$	$q^2 \in [1.1, 6.0], [15.0, 22.0]$ GeV^2	LHCb 1403.8045
	F_H^μ	$q^2 \in [1.1, 6.0], [15.0, 22.0]$ GeV^2	LHCb 1403.8045
	$A_{\rm CP}$	$q^2 \in [1.1, 6.0], [15.0, 22.0]$ GeV^2	LHCb 1408.0978
$B^0 \to K^{*0}\bar{\mu}\mu$	Br	$q^2 \in [1, 6], [14.18, 16], [> 16]$ GeV^2	CDF, LHCb, CMS $^{\dagger)}$
	$A_{\rm CP}$	$q^2 \in [1.1, 6.0], [15.0, 22.0]$ GeV^2	LHCb 1408.0978

$^{\dagger)}$CDF, LHCb, CMS = Public note 10894, 1304.6325, 1308.3409

Scenario T + T5 (preliminary)

flat prior for Re, Im$(C_{T,T5}) \in [-1.0, 1.0]$

data set	only F_H^μ @ low- and high-q^2	F_H^μ + $B \to K^{(*)}\bar{\ell}\ell$: Br, A_{CP}
scenario	$C_{T,\,T5}$	$C_{T,\,T5}$ + $C_{9,10}$ with Re, Im$(C_i^{NP}) \in [-7, 7]$
Re C_T	$[-0.32, 0.16]$ ($[-0.52, 0.35]$)	$[-0.20, 0.20]$ ($[-0.40, 0.35]$)
Im C_T	$[-0.25, 0.24]$ ($[-0.44, 0.44]$)	$[-0.20, 0.20]$ ($[-0.35, 0.35]$)
Re C_{T5}	$[-0.25, 0.24]$ ($[-0.44, 0.44]$)	$[-0.20, 0.15]$ ($[-0.35, 0.35]$)
Im C_{T5}	$[-0.24, 0.25]$ ($[-0.44, 0.45]$)	$[-0.20, 0.20]$ ($[-0.35, 0.35]$)
$\|C_T\|, \|C_{T5}\|$	$[0.13, 0.43]$ ($[0.03, 0.57]$)	< 0.30 (< 0.45)

1D-marginalized at 68% (95%) probability intervals for complex-valued $C_{T,\,T5}$

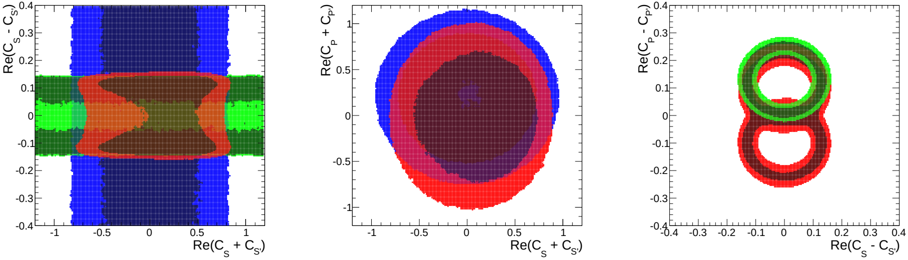
Even allowing for interference with vectorial couplings ⇒ F_H (3/fb) imposes bounds

$$|C_T|, |C_{T5}| < 0.30\,(0.45) \text{ @ } 68\%\ (95\%)$$

(previous bound $|C_T|, |C_{T5}| < 0.5\,(0.7)$ from LHCb 1/fb [CB/Hiller/van Dyk arXiv:1212.2321])

Scenario S + P (preliminary)

flat prior for $\mathrm{Re}, \mathrm{Im}(C_{S('),P('))}) \in [-1.0, 1.0]$



green — only $Br(B_s \to \bar{\mu}\mu)$

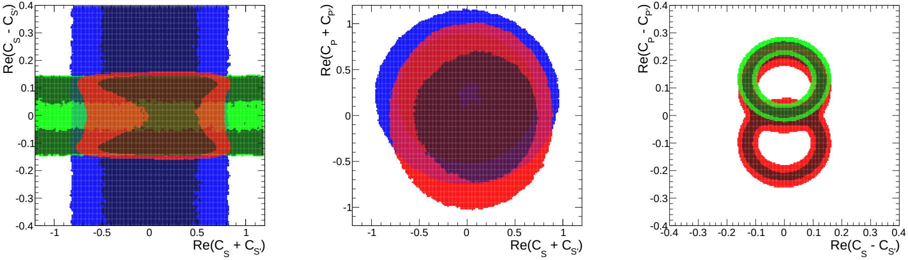
blue — only $F_H(B^+ \to K^+\bar{\mu}\mu)$

red — all data

$+ \mathrm{Re}, \mathrm{Im}(C_{10,10'}^{\mathrm{NP}}) \in [-5, 5]$

Scenario S + P (preliminary)

flat prior for Re, Im$(C_{S('),P('')})\in[-1.0,\,1.0]$



$|C_i + C_{i'}| < 0.4\,(0.7)$ for $i = S,\ P$

$|C_i - C_{i'}| < 0.1\,(0.2)$ @ 68% (95%)

green	only $Br(B_s \to \bar{\mu}\mu)$
blue	only $F_H(B^+ \to K^+\bar{\mu}\mu)$
red	all data
	+ Re, Im$(C^{\rm NP}_{10,10'})\in[-5,\,5]$

!!! Combined measurements of
$Br(B_s \to \bar{\mu}\mu)$ & F_H
allow to constrain simultaneously
complex-valued $C_{S,S',P,P'}$
even for interference with $C_{10,10'}$

Predictions for $B \to K^* \bar{\ell}\ell$ (preliminary)

For comparison: the rate is $\sim \mathcal{O}(10^{-19})$ in SM exp. precision 1/fb $\approx$ 18%

$$\frac{d\Gamma}{dq^2} = \frac{2}{3}(3J_{1s} - J_{2s}) + \frac{1}{3}(3J_{1c} - J_{2c}) \quad \Rightarrow \quad \langle d\Gamma/dq^2\rangle_{[1.1,\,6]} = (1.1 \pm 0.3) \cdot 10^{-19}$$

SM predictions

$$J_{6c} \simeq 0 + \mathcal{O}(\alpha_e) + \mathcal{O}(\dim 8)$$

$$(J_{1s} - 3J_{2s})_{[1.1,\,6]} = (2.0^{+0.6}_{-0.5}) \cdot 10^{-22} \qquad (J_{1c} + J_{2c})_{[1.1,\,6]} = (1.8 \pm 0.3) \cdot 10^{-21}$$

$$(J_{1s} - 3J_{2s})_{[15,\,19]} = (0.6 \pm 0.1) \cdot 10^{-22} \qquad (J_{1c} + J_{2c})_{[15,\,19]} = (8.8^{+2.1}_{-1.8}) \cdot 10^{-23}$$

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Beyond SM Yet still allowed ranges @ 68% probability in various scenarios

observable	q^2-bin	$9, 10, T, T5$	$10^{(\prime)}, S^{(\prime)}, P^{(\prime)}$	$10^{(\prime)}, S^{(\prime)}, P^{(\prime)}, T, T5$
J_{6c}	[1.1, 6]	$(-1.3^{+3.1}_{-0.6}) \cdot 10^{-21}$	$(0.1^{+0.6}_{-1.2}) \cdot 10^{-22}$	$(0.7^{+0.5}_{-2.0}) \cdot 10^{-21}$
	[15, 19]	$(-0.4^{+1.1}_{-0.3}) \cdot 10^{-21}$	$(-0.3^{+0.2}_{-0.0}) \cdot 10^{-22}$	$(-0.3^{+0.7}_{-0.2}) \cdot 10^{-21}$
$J_{1s} - 3J_{2s}$	[1.1, 6]	$(1.5^{+0.8}_{-0.6}) \cdot 10^{-20}$	SM	$(2.0^{+1.0}_{-1.0}) \cdot 10^{-20}$
	[15, 19]	$(6.6^{+3.4}_{-2.7}) \cdot 10^{-21}$	SM	$(9.3^{+3.9}_{-4.5}) \cdot 10^{-21}$
$J_{1c} + J_{2c}$	[1.1, 6]	$(3.0^{+1.3}_{-1.0}) \cdot 10^{-21}$	$(1.2^{+0.3}_{-0.2}) \cdot 10^{-21}$	$(3.2^{+2.4}_{-1.3}) \cdot 10^{-21}$
	[15, 19]	$(5.6^{+3.3}_{-2.6}) \cdot 10^{-21}$	$(7.5^{+1.0}_{-2.0}) \cdot 10^{-23}$	$(7.3^{+5.2}_{-3.3}) \cdot 10^{-21}$

⇒ good prospects for T + T5: $(J_{1s} - 3J_{2s}) \lesssim 3.0 \cdot 10^{-20}$ $(J_{1c} + J_{2c}) \lesssim 1.2 \cdot 10^{-20}$

⇒ sensitivity to S + P much less in J_{6c} and $(J_{1c} + J_{2c})$

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There are observables in $b \to s\bar{\ell}\ell$ with enhanced sensitivity to scalar and tensorial cpl's

- $B_s \to \bar{\mu}\mu$: Br $(A_{\Delta\Gamma})$
- $B \to K\bar{\ell}\ell$: F_H, A_{FB}
- $B \to K^*\bar{\ell}\ell$: $(J_{1s} - 3J_{2s})$, $(J_{1c} + J_{2c})$ and J_{6c}

due to $m_\ell/\sqrt{q^2}$ suppression of vectorial cpl's (∼ "SM background")

⇒ orthogonal to observables dominated by vectorial couplings

⇒ allow to constrain scalar and tensorial couplings (almost independent fit)

- F_H measurement imposes constraints on T + T5:

  $|C_{T,T5}| < 0.35\,(0.45)$ @ 68% (95%) **(preliminary)**

- F_H combined with $Br(B_s \to \bar{\mu}\mu)$ for the first time simultaneous bound on $C_{S,S',P,P'}$ (complex-valued):

  $|C_i + C_{i'}| < 0.4\,(0.7)$ and $|C_i - C_{i'}| < 0.1\,(0.2)$ **(preliminary)**

Please measure $(J_{1s} - 3J_{2s})$, $(J_{1c} + J_{2c})$ and J_{6c} without assuming $C_{S,P,T} = 0$ and $m_\ell = 0$

Fits with **EOS** = HEP Flavour tool

@ **http://project.het.physik.tu-dortmund.de/eos/**

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