Observables of Interest and Global Fits for $b \longrightarrow s$ Transitions

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Flavor of NP in $b \longrightarrow s$ transitions

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Theor. Physik 1

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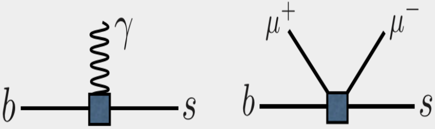
Radiative and Dileptonic $b \to s$ Operators

Radiative and Dileptonic $b \to s$ Operators

$$\mathcal{O}_{7(\prime)} = [\bar{s}\sigma^{\mu\nu}P_{R(L)}b]F_{\mu\nu}$$
$$\mathcal{O}_{9(\prime)} = [\bar{s}\gamma^{\mu}P_{L(R)}b][\bar{\ell}\gamma_{\mu}\ell]$$
$$\mathcal{O}_{10(\prime)} = [\bar{s}\gamma^{\mu}P_{L(R)}b][\bar{\ell}\gamma_{\mu}\gamma_5\ell]$$



Effective Hamiltonian

$$\mathcal{H}_{\rm eff}^{\rm sl} = -\frac{4G_F}{\sqrt{2}}V_{tb}V_{ts}^*\Big[\mathcal{C}_7\mathcal{O}_7 + \mathcal{C}_{7'}\mathcal{O}_{7'} + \mathcal{C}_9\mathcal{O}_9 + \mathcal{C}_{9'}\mathcal{O}_{9'} + \mathcal{C}_{10}\mathcal{O}_{10} + \mathcal{C}_{10'}\mathcal{O}_{10'}\Big]$$

Note: We write $\mathcal{C}_i = \mathcal{C}_i^{\rm SM} + \mathcal{C}_i^{\rm NP}$:

$$\mathcal{C}_{7\rm eff}^{\rm SM} = -0.29,\ \mathcal{C}_9^{\rm SM} = 4.07,\ \mathcal{C}_{10}^{\rm SM} = -4.31,\ \mathcal{C}_{i'}^{\rm SM} \simeq 0$$

Radiative and Dileptonic $b \to s$ Operators

How to Measure Radiative and Dileptonic Operators?

1. Identify decay modes and observables most sensitive to such ops

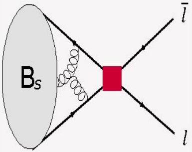
Decay modes for $b \to s\gamma$ and $b \to s\ell\ell$

$B \to X_s\gamma$	$B \to X_s\ell\ell$	$B_s \to \ell^+\ell^-$
$B \to K^*\gamma$	$B \to K^*\ell\ell$	$B \to K\ell\ell$

2. Compute the observables in the effective theory
3. Compute/fit/estimate/get all <u>non-perturbative parameters</u>.
4. Fit the data, extract CL intervals for the $\mathcal{C}_i(m_b)$.
5. Interpret the results.

Note: We will fit directly to $\mathcal{C}_i^{\mathrm{NP}}(m_b)$

$$\mathcal{L} = \mathcal{L}_{QED+QCD} + \mathcal{C}_9^{(\prime)}\,[\bar{s}\gamma^\mu P_{L(R)} b]\,[\bar{\ell}\gamma_\mu \ell] + \mathcal{C}_{10}^{(\prime)}\,[\bar{s}\gamma^\mu P_{L(R)} b]\,[\bar{\ell}\gamma_\mu\gamma_5 \ell] + \cdots$$



$$\mathcal{A}_9^{(\prime)} = \mathcal{C}_9^{(\prime)}\,\langle \bar{\ell}\ell|\bar{\ell}\gamma_\mu\ell|0\rangle\,\underbrace{\langle 0|\bar{s}\gamma^\mu P_{L(R)} b|B_s\rangle}_{\sim p_B^\mu = p_\ell^\mu + p_{\bar{\ell}}^\mu} = 0 + \mathcal{O}(\alpha)$$

Contributions from $\mathcal{O}_7$ and other 4-quark ops are zero like $\mathcal{A}_9^{(\prime)}$.

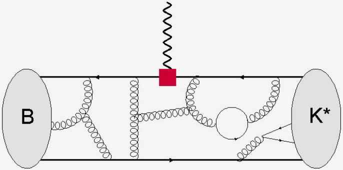
$$\to \mathcal{A}_{10}^{(\prime)} = \mathcal{C}_{10}^{(\prime)}\,\langle \bar{\ell}\ell|\bar{\ell}\gamma_\mu\gamma_5\ell|0\rangle\langle 0|\bar{s}\gamma^\mu P_{L(R)} b|B_s\rangle = \mp i f_{B_s}\mathcal{C}_{10}^{(\prime)}\, m_\ell\,[\bar{u}_\ell\gamma_5 v_{\bar{\ell}}]$$

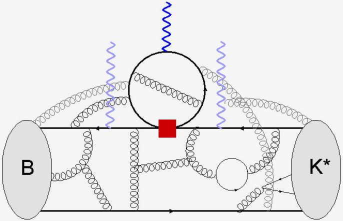
$$\to \sum_{\text{spins}} |\mathcal{A}_{10} + \mathcal{A}'_{10}|^2 = 2 f_{B_s}^2 m_{B_s}^2 m_\ell^2\,|\mathcal{C}_{10} - \mathcal{C}'_{10}|^2$$

$$\to BR(B_s \to \ell\bar{\ell}) = \frac{\tau_{B_s} f_{B_s}^2 m_{B_s}^3}{8\pi}\,\frac{m_\ell^2}{m_{B_s}^2}\sqrt{1 - \frac{4m_\ell^2}{m_{B_s}^2}}\;|\mathcal{C}_{10} - \mathcal{C}'_{10}|^2$$

<u>**Note:**</u> Contributions from (pseudo)SCALAR operators are **not helicity suppressed**.

$$\mathcal{L} = \mathcal{L}_{QED+QCD} + \mathcal{C}_7\,[\bar{s}\sigma^{\mu\nu}P_R b]\,F_{\mu\nu} + \mathcal{C}_2\,[\bar{s}\gamma^\nu P_L c]\,[\bar{c}\gamma^\mu P_L b] + \cdots$$





$\mathcal{C}_7$ **contribution:** $\mathcal{A}_7 = \mathcal{C}_7\,\langle K^*_\lambda|\bar{s}\sigma_{\mu\nu}P_R b|B\rangle q^\mu \epsilon^\nu_\lambda = \mathcal{C}_7\,T_\lambda(q^2)$

$\mathcal{C}_2$ **contribution:** $\mathcal{A}_2 = \mathcal{C}_2 \cdot \epsilon^{*\mu}_\lambda \int dx^4 e^{iq\cdot x}\langle K^*_\lambda|\,T\{j^{c\bar{c}}_\mu(x)\mathcal{O}_2(0)\}|B\rangle$

Note: There are similar contributions from $\mathcal{O}_8$ and other 4-quark ops.
These operators are contained in what we call $\mathcal{H}^{\rm had}_{\rm eff}$.

$$\mathcal{A}_9^{(\prime)} = \mathcal{C}_9^{(\prime)} \langle \bar{\ell}\ell|\bar{\ell}\gamma_\mu \ell|0\rangle\langle K|\bar{s}\gamma^\mu P_{L(R)} b|B\rangle \;=\; \mathcal{C}_9^{(\prime)} f_+(q^2)\, [\bar{u}_\ell \not{p} v_{\bar{\ell}}]$$

$$\mathcal{A}_{10}^{(\prime)} = \mathcal{C}_{10}^{(\prime)} \langle \bar{\ell}\ell|\bar{\ell}\gamma_\mu \gamma_5 \ell|0\rangle\langle K|\bar{s}\gamma^\mu P_{L(R)} b|B\rangle = \mathcal{C}_{10}^{(\prime)} f_+(q^2)\, [\bar{u}_\ell \not{p}\gamma_5 v_{\bar{\ell}}]$$

$$\mathcal{A}_7^{(\prime)} = \mathcal{C}_7^{(\prime)} \langle \bar{\ell}\ell|\bar{\ell}\gamma_\mu \ell|0\rangle \frac{-i}{q^2}\langle K|\bar{s} q_\mu \sigma^{\mu\nu} P_{R(L)} b|B\rangle = \mathcal{C}_7^{(\prime)} \frac{f_T(q^2)}{m_B + m_K} [\bar{u}_\ell \not{p} v_{\bar{\ell}}]$$

$$\mathcal{A}_{\rm had} = \mathcal{K}(q^2)[\bar{u}_\ell \not{p} v_{\bar{\ell}}]$$

$$\mathcal{A}(B \to K\ell\bar{\ell}) = a_9\, [\bar{u}_\ell \not{p} v_{\bar{\ell}}] + a_{10}\, [\bar{u}_\ell \not{p}\gamma_5 v_{\bar{\ell}}]$$

$$a_9 = (\mathcal{C}_9 + \mathcal{C}_9')\, f_+(q^2) + (\mathcal{C}_7 + \mathcal{C}_7')\, \frac{f_T(q^2)}{m_B+m_K} + \mathcal{K}(q^2)\; ; \quad a_{10} = (\mathcal{C}_{10} + \mathcal{C}_{10}')\, f_+(q^2)$$

$$\frac{d\Gamma}{ds_{13}\, ds_{23}} = \frac{m_B^5}{2^8\pi^3}(|a_9|^2 + |a_{10}|^2) s_{13} s_{23}$$

Where $s_{13} = 2p_\ell \cdot p_K/m_B^2$, $s_{23} = 2p_{\bar{\ell}} \cdot p_K/m_B^2$ – $s_{12} = q^2/m_B^2$

Structure of the Decay Amplitude

"Semileptonic" contribution $\longrightarrow$ New Physics

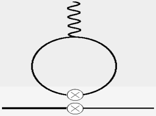
$$\langle K^*\ell\ell|\mathcal{O}_{9^{(\prime)},10^{(\prime)}}|B\rangle = \langle \ell^+\ell^-|\bar\ell\gamma_\mu(\gamma_5)\ell|0\rangle\langle K^*|\bar s\gamma^\mu P_{L,R}b|B\rangle \sim F_{i,\lambda}^{B\to K*}(q^2)$$

$$\langle K^*\ell\ell|T\{j^\ell_{em}\mathcal{O}_{7^{(\prime)}}\}|B\rangle = \langle \ell^+\ell^-|\bar\ell\gamma_\mu\ell|0\rangle\frac{q_\nu}{q^2}\langle K^*|\bar s\sigma^{\mu\nu}P_{R,L}b|B\rangle \sim T_{i,\lambda}^{B\to K*}(q^2)$$

$$\mathcal{A}^{\rm sl} = \sum_i f_i(\mathcal{C}_{7^{(\prime)}},\mathcal{C}_{9^{(\prime)}},\mathcal{C}_{10^{(\prime)}}) \times (\text{Form Factor})_i$$

"Hadronic" contribution $\longrightarrow$ QCD $[\mathcal{C}_{1,2},\mathcal{C}_8,\mathcal{C}_{3,4,5,6}]$

$$\mathcal{A}^{\rm had} = i\frac{e^2}{q^2}\langle \ell^+\ell^-|\bar\ell\gamma_\mu\ell|0\rangle\int d^4x e^{iq\cdot x}\langle K^*|T\{j^\mu_{em}(x)\mathcal{H}^{\rm had}_{\rm eff}(0)\}|B\rangle$$



2 main problems:

1. Precise determination of Form Factors (LCSRs, LQCD, . . .)
2. Computation of the hadronic contribution (SCET/QCDF, OPE, . . .)

Optimized Observables

Several Form Factor ratios can be predicted:

- At large recoil $\longrightarrow$ SCET   Charles et.al. hep-ph/9812358, Beneke, Feldmann, hep-ph/0008255
- At low recoil $\longrightarrow$ HQET   Grinstein, Pirjol, hep-ph/0404250, Bobeth, Hiller, van Dyk

Example   SCET relation at large recoil

$$\frac{\epsilon_-^{*\mu} q^\nu \langle K_-^* | \bar{s}\sigma_{\mu\nu} P_R b | B\rangle}{i m_B \langle K_-^* | \bar{s} \not\epsilon_-^* P_L b | B\rangle} = 1 + \mathcal{O}(\alpha_s, \Lambda/m_b)$$

This allows to build observables with **reduced dependence on FFs**.

Optimized observables at large recoil   Matias, Mescia, Ramon, JV – 1202.4266; Descotes-Genon, Matias, Ramon, JV – 1207.2753

$$P_1 = \frac{J_3}{2J_{2s}} \qquad P_2 = \frac{J_{6s}}{8J_{2s}} \qquad P_4' = \frac{J_4}{\sqrt{-J_{2s}J_{2c}}}$$

$$P_5' = \frac{J_5}{2\sqrt{-J_{2s}J_{2c}}} \qquad P_6' = \frac{-J_7}{2\sqrt{-J_{2s}J_{2c}}} \qquad P_8' = \frac{-J_8}{\sqrt{-J_{2s}J_{2c}}}$$

Fitting the data: Set of data and pulls

Observable	Experiment	SM prediction	Pull
$\langle P_1\rangle_{[0.1,2]}$	$-0.19^{+0.40}_{-0.35}$	$0.007^{+0.043}_{-0.044}$	-0.5
$\langle P_1\rangle_{[2,4.3]}$	$-0.29^{+0.65}_{-0.46}$	$-0.051^{+0.046}_{-0.046}$	-0.4
$\langle P_1\rangle_{[4.3,8.68]}$	$0.36^{+0.30}_{-0.31}$	$-0.117^{+0.056}_{-0.052}$	$+1.5$
$\langle P_1\rangle_{[1,6]}$	$0.15^{+0.39}_{-0.41}$	$-0.055^{+0.041}_{-0.043}$	$+0.5$
$\langle P_2\rangle_{[0.1,2]}$	$0.03^{+0.14}_{-0.15}$	$0.172^{+0.020}_{-0.021}$	-1.0
$\langle P_2\rangle_{[2,4.3]}$	$0.50^{+0.00}_{-0.07}$	$0.234^{+0.060}_{-0.086}$	$+2.9$
$\langle P_2\rangle_{[4.3,8.68]}$	$-0.25^{+0.07}_{-0.08}$	$-0.407^{+0.049}_{-0.037}$	$+1.7$
$\langle P_2\rangle_{[1,6]}$	$0.33^{+0.11}_{-0.12}$	$0.084^{+0.060}_{-0.078}$	$+1.8$
$\langle P_4'\rangle_{[0.1,2]}$	$0.00^{+0.52}_{-0.52}$	$-0.342^{+0.031}_{-0.026}$	$+0.7$
$\langle P_4'\rangle_{[2,4.3]}$	$0.74^{+0.54}_{-0.60}$	$0.569^{+0.073}_{-0.063}$	$+0.3$
$\langle P_4'\rangle_{[4.3,8.68]}$	$1.18^{+0.26}_{-0.32}$	$1.003^{+0.028}_{-0.032}$	$+0.6$
$\langle P_4'\rangle_{[1,6]}$	$0.58^{+0.32}_{-0.36}$	$0.555^{+0.067}_{-0.058}$	$+0.1$
$\langle P_5'\rangle_{[0.1,2]}$	$0.45^{+0.21}_{-0.24}$	$0.533^{+0.033}_{-0.041}$	-0.4
$\langle P_5'\rangle_{[2,4.3]}$	$0.29^{+0.40}_{-0.39}$	$-0.334^{+0.097}_{-0.113}$	$+1.6$
$\langle P_5'\rangle_{[4.3,8.68]}$	$-0.19^{+0.16}_{-0.16}$	$-0.872^{+0.053}_{-0.041}$	$+4.0$
$\langle P_5'\rangle_{[1,6]}$	$0.21^{+0.20}_{-0.21}$	$-0.349^{+0.088}_{-0.100}$	$+2.5$
$\langle P_6'\rangle_{[0.1,2]}$	$0.24^{+0.23}_{-0.20}$	$-0.084^{+0.034}_{-0.044}$	$+1.6$
$\langle P_6'\rangle_{[2,4.3]}$	$-0.15^{+0.38}_{-0.36}$	$-0.098^{+0.043}_{-0.056}$	-0.1
$\langle P_6'\rangle_{[4.3,8.68]}$	$0.04^{+0.16}_{-0.16}$	$-0.027^{+0.060}_{-0.063}$	$+0.4$
$\langle P_6'\rangle_{[1,6]}$	$0.18^{+0.21}_{-0.21}$	$-0.089^{+0.042}_{-0.052}$	$+1.3$
$\langle P_8'\rangle_{[0.1,2]}$	$-0.12^{+0.56}_{-0.56}$	$0.037^{+0.037}_{-0.030}$	-0.3
$\langle P_8'\rangle_{[2,4.3]}$	$-0.30^{+0.60}_{-0.58}$	$0.070^{+0.045}_{-0.034}$	-0.6
$\langle P_8'\rangle_{[4.3,8.68]}$	$0.58^{+0.34}_{-0.38}$	$0.020^{+0.054}_{-0.055}$	$+1.5$
$\langle P_8'\rangle_{[1,6]}$	$0.46^{+0.36}_{-0.38}$	$0.063^{+0.042}_{-0.033}$	$+1.0$
$\langle A_{\rm FB}\rangle_{[0.1,2]}$	$-0.02^{+0.13}_{-0.13}$	$-0.136^{+0.051}_{-0.048}$	$+0.8$
$\langle A_{\rm FB}\rangle_{[2,4.3]}$	$-0.20^{+0.08}_{-0.08}$	$-0.081^{+0.055}_{-0.069}$	-1.1
$\langle A_{\rm FB}\rangle_{[4.3,8.68]}$	$0.16^{+0.06}_{-0.05}$	$0.220^{+0.138}_{-0.113}$	-0.5
$\langle A_{\rm FB}\rangle_{[1,6]}$	$-0.17^{+0.06}_{-0.06}$	$-0.035^{+0.037}_{-0.034}$	-2.0

Observable	Experiment	SM prediction	Pull
$\langle P_1\rangle_{[14.18,16]}$	$0.07^{+0.26}_{-0.28}$	$-0.352^{+0.697}_{-0.468}$	$+0.6$
$\langle P_1\rangle_{[16,19]}$	$-0.71^{+0.36}_{-0.26}$	$-0.603^{+0.589}_{-0.315}$	-0.2
$\langle P_2\rangle_{[14.18,16]}$	$-0.50^{+0.03}_{-0.00}$	$-0.449^{+0.136}_{-0.041}$	-1.1
$\langle P_2\rangle_{[16,19]}$	$-0.32^{+0.08}_{-0.08}$	$-0.374^{+0.151}_{-0.126}$	$+0.3$
$\langle P_4'\rangle_{[14.18,16]}$	$-0.18^{+0.54}_{-0.70}$	$1.161^{+0.190}_{-0.332}$	-2.1
$\langle P_4'\rangle_{[16,19]}$	$0.70^{+0.44}_{-0.52}$	$1.263^{+0.119}_{-0.248}$	-1.1
$\langle P_5'\rangle_{[14.18,16]}$	$-0.79^{+0.27}_{-0.22}$	$-0.779^{+0.328}_{-0.363}$	$+0.0$
$\langle P_5'\rangle_{[16,19]}$	$-0.60^{+0.21}_{-0.18}$	$-0.601^{+0.282}_{-0.367}$	$+0.0$
$\langle P_6'\rangle_{[14.18,16]}$	$0.18^{+0.24}_{-0.25}$	$0.000^{+0.000}_{-0.000}$	$+0.7$
$\langle P_6'\rangle_{[16,19]}$	$-0.31^{+0.38}_{-0.39}$	$0.000^{+0.000}_{-0.000}$	-0.8
$\langle P_8'\rangle_{[14.18,16]}$	$-0.40^{+0.60}_{-0.50}$	$-0.015^{+0.009}_{-0.013}$	-0.6
$\langle P_8'\rangle_{[16,19]}$	$0.12^{+0.52}_{-0.54}$	$-0.008^{+0.005}_{-0.007}$	$+0.2$
$\langle A_{\rm FB}\rangle_{[14.18,16]}$	$0.51^{+0.07}_{-0.05}$	$0.404^{+0.199}_{-0.191}$	$+0.5$
$\langle A_{\rm FB}\rangle_{[16,19]}$	$0.30^{+0.08}_{-0.08}$	$0.360^{+0.205}_{-0.172}$	-0.3
$10^4\,\mathcal{B}_{B\to X_s\gamma}$	3.43 ± 0.22	3.15 ± 0.23	$+0.9$
$10^6\,\mathcal{B}_{B\to X_s\mu^+\mu^-}$	1.60 ± 0.50	1.59 ± 0.11	$+0.0$
$10^9\,\mathcal{B}_{B_s\to\mu^+\mu^-}$	2.9 ± 0.8	3.56 ± 0.18	-0.8
$A_I(B\to K^*\gamma)$	0.052 ± 0.026	0.041 ± 0.025	$+0.3$
$S_{K^*\gamma}$	-0.16 ± 0.22	-0.03 ± 0.01	-0.6

S. Descotes-Genon, J. Matias, JV – 1307.5683

Fitting the data: Set-up

Strategy:

We fit to **47** observables by means of a frequentist χ^2 approach.

Observables included in the analysis

$$BR(B \to X_s\gamma), \quad BR(B \to X_s\mu^+\mu^-)_{Low\ q^2}$$

$$BR(B_s \to \mu^+\mu^-), \quad A_I(B \to K^*\gamma), \quad S(B \to K^*\gamma)$$

$$B \to K^*\mu^+\mu^- : \ \langle P_1\rangle, \langle P_2\rangle, \langle P_4'\rangle, \langle P_5'\rangle, \langle P_6'\rangle, \langle P_8'\rangle, \langle A_{\rm FB}\rangle$$

in several different bins

Observables *not* included in the analysis

$$B \to K\mu^+\mu^-, \quad B_s \to \phi\mu^+\mu^-, \quad B \to X_s\mu^+\mu^- \text{ @ } Large\ q^2, \ \ldots$$

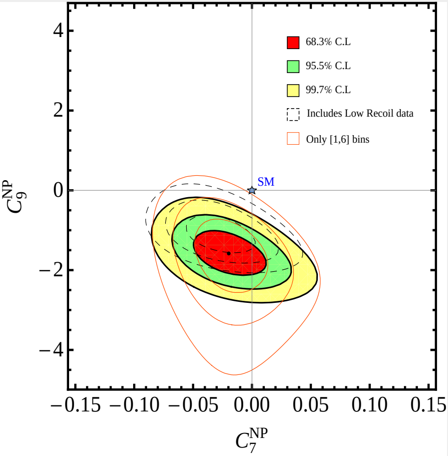
not considered for different reasons

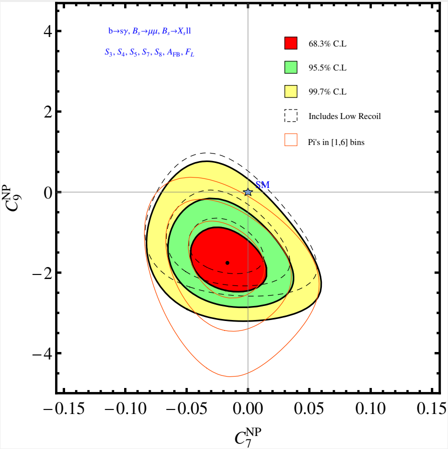
General Fit

Coefficient	$1\,\sigma$	$2\,\sigma$	$3\,\sigma$
$\mathcal{C}_7^{\rm NP}$	$[-0.05, -0.01]$	$[-0.06, 0.01]$	$[-0.08, 0.03]$
$\mathcal{C}_9^{\rm NP}$	$[-1.6, -0.9]$	$[-1.8, -0.6]$	$[-2.1, -0.2]$
$\mathcal{C}_{10}^{\rm NP}$	$[-0.4, 1.0]$	$[-1.2, 2.0]$	$[-2.0, 3.0]$
$\mathcal{C}_{7'}^{\rm NP}$	$[-0.04, 0.02]$	$[-0.09, 0.06]$	$[-0.14, 0.10]$
$\mathcal{C}_{9'}^{\rm NP}$	$[-0.2, 0.8]$	$[-0.8, 1.4]$	$[-1.2, 1.8]$
$\mathcal{C}_{10'}^{\rm NP}$	$[-0.4, 0.4]$	$[-1.0, 0.8]$	$[-1.4, 1.2]$

- Negative values for $(\mathcal{C}_7^{\rm NP}, \mathcal{C}_9^{\rm NP})$ favoured at $>$ (1σ,**3σ**).
- Large-recoil only $\longrightarrow$ effect enhanced ($\mathcal{C}_9^{\rm NP} \sim -1.6$).
- Only [1-6] bin: Same pattern, less significance.

$\mathcal{C}_7^{\rm NP}$- $\mathcal{C}_9^{\rm NP}$ Scenario



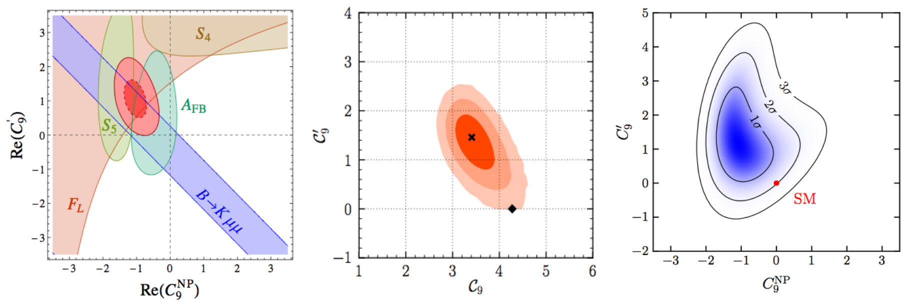


Summary so far

- A global fit to $b \to s\gamma$, $b \to s\mu\mu$ observables including the latest data on $B \to K^*\mu\mu$ angular observables shows some level of tension w.r.t the SM, pointing (mostly) to a large NP contribution to $\mathcal{C}_9$.

  S. Descotes-Genon, J. Matias, JV – 1307.5683

- This has been later confirmed by other groups



Altmannshofer, Straub 1308.1501, Beaujean, Bobeth, van Dyk 1310.2478, Horgan et al. 1310.3887

ISSUES

1. Factorizable power corrections.

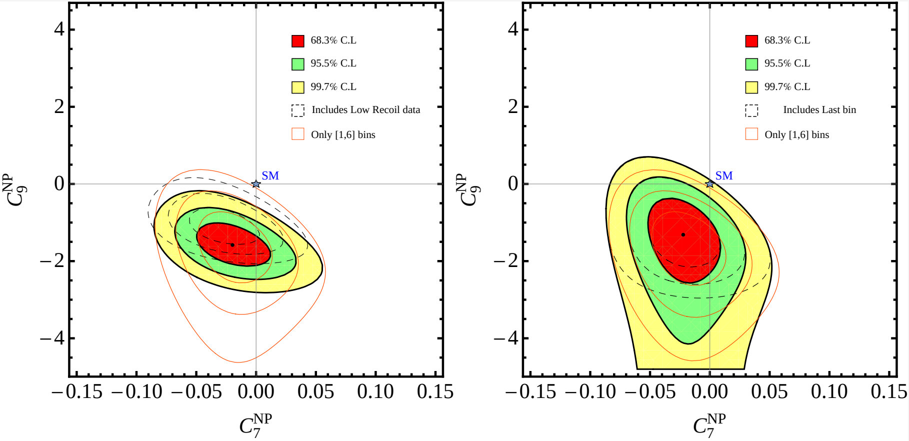
2. Theory correlations and Form Factors.

3. Non-factorizable corrections $(\mathcal{K}(q^2)$ and $c\bar{c}$-loop).

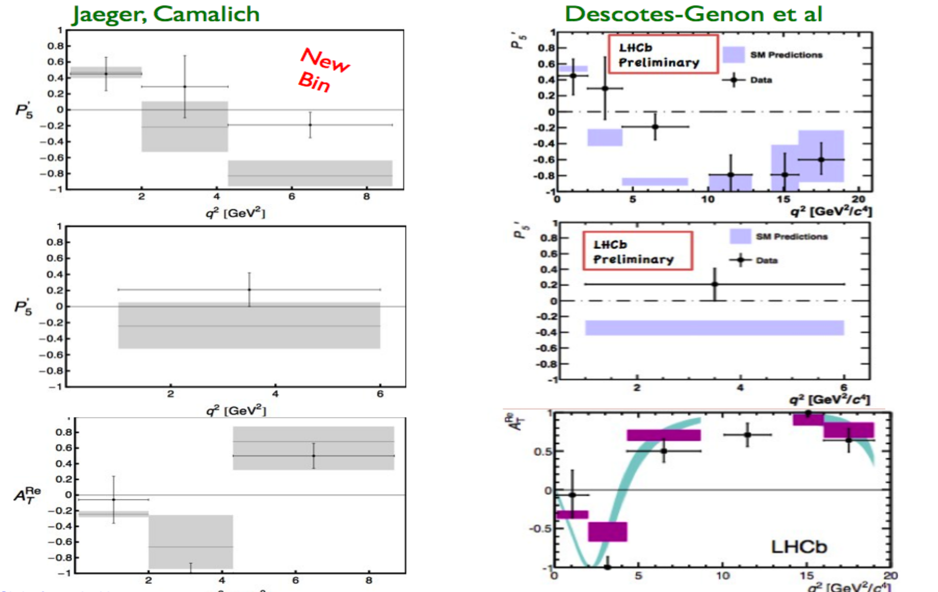
4. Binning.

5. Non-resonant backgrounds.

Excluding the [4.3,8.68] bin



Factorizable Power Corrections



Slide from A. Kagan

Factorizable Power Corrections

$$\mathcal{A} = \left[\mathcal{C}_9^{\pm} + Y(q^2) + \mathcal{C}_{10}^{\pm}\right] V(q^2) + \frac{2m_b}{q^2}\left[\mathcal{C}_7^{\pm} T_1(q^2) + \mathcal{T}^{nf}\right]$$

Possibilities:

1. "Munich" approach: $V, T_1, A_{0,1,2}, T_{2,3}$ from LCSRs, $\mathcal{T}^{nf}$ from QCDF
   - Little scheme dependence.
   - No factorizable power corrections.
   - No "clean" observables: *correlations* among Form Factors crucial.
2. "Aachen" approach: $V, T_1, A_{0,1,2}, T_{2,3} \longrightarrow \xi_\perp, \xi_\|$, $\mathcal{T}^{nf}$ from QCDF
   - "Clean" observables at work.
   - Factorizable power corrections.
   - Scheme dependence $(\xi_\perp, \xi_\|) \leftrightarrow (V, A_1 - A_2)$, (V, A_0), $(T_1, A0)$, etc.
     "Measure" of symmetry-breaking power corrections.

Factorizable Power Corrections

Jager, Camalich 2012: First attempt to more serious estimates of the effect of Fact.PCs in $B \to K^* \ell\ell$ observables.

Idea: The amount of breaking of large-recoil Form-Factor relations as computed from non-perturbative methods (LCSRs, DSE..) measures Factorizable PCs.

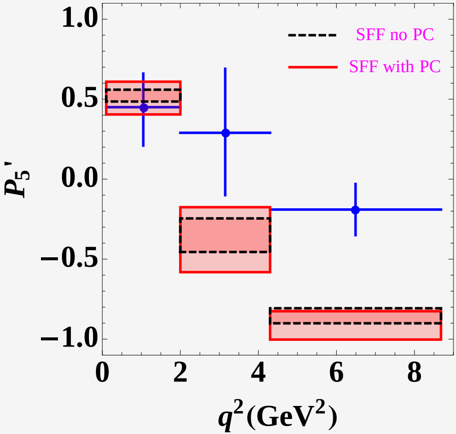
Our position: We like the idea!

- Not just *estimate* an *absolute* error: compute central values and $\pm$.
- Careful: Deviations among different non-perturbative determinations are **not** a measure of power corrections.
- Our approach: Compute central values for Factorizable PCs within each LCSR determination *separately*, in different *schemes* for soft FFs, to get a more clear picture of the effect of PCs on the observables.

Without precise theoretical correlations among different FFs and different determinations, this is the best one can do.

Factorizable Power Corrections

Scheme 1:
$$V(s) = (1 + m_{K^*}/m_B)\, \xi_\perp$$
$$T_1(s) = \xi_\perp + \Delta T_1^{\alpha_s} + a_{T_1} + b_{T_1}(s/m_B) + c_{T_1}(s/m_B)^2$$



- $a_{T_1} = \hat{a}_{T_1} \pm 0.1\, T_1$, etc.
- Determine errors from FF should be equivalent to "Munich" approach (?)
- Are some schemes better than others?
- If we have all theory correlations: do we need clean observables?
- We need to compute PCs.

Factorizable Power Corrections

Form-Factor correlations and clean observables:

$$\left.\frac{\epsilon_-^{*\mu} q^\nu \langle K_-^* | \bar{s}\sigma_{\mu\nu} P_R b | B\rangle}{i m_B \langle K_-^* | \bar{s} \not{\epsilon}_-^* P_L b | B\rangle}\right|_{\rm SCET} = 1 + \mathcal{O}(\alpha_s) + \mathcal{O}(\Lambda/m_b)$$

$$\left.\frac{\epsilon_-^{*\mu} q^\nu \langle K_-^* | \bar{s}\sigma_{\mu\nu} P_R b | B\rangle}{i m_B \langle K_-^* | \bar{s} \not{\epsilon}_-^* P_L b | B\rangle}\right|_{\rm LCSR} = R \pm \Delta$$

Questions:

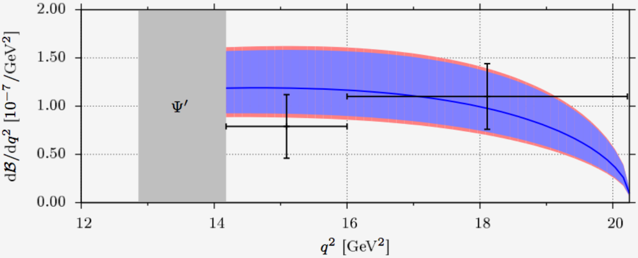
- Is $R - 1 - \mathcal{O}(\alpha_s)$ compare with the expected size of PCs?
- Is Δ "too large"? (whatever that means)

Other $b \to s\ell\ell$ Observables

Hadronic effects are process-dependent, $\mathcal{C}_9$ is not $\to$ need to study many other exclusive modes, some examples:

- $B_s \to \phi\mu^+\mu^-$ Horgan et al. 1310.3887; Hiller, Hambrock, w.i.p.
- $\Lambda_b \to \Lambda\mu^+\mu^-$ Böer, Feldmann, van Dyk, w.i.p.

Λ decays weakly ($\Lambda \to p\pi$), $s = 1/2$, diff. ang. dist than $B \to K^*$.



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- $\Omega_b \to \Omega^-\mu^+\mu^-$ w.i.p.

  Ω^- decays weakly ($\Omega^- \to \Lambda K^-$), $s = 3/2$, diff. ang. dist.