Anomalies in $b \to s\ell\ell$ and Global Fits

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Rare B Decays:

- FCNCs (leptonic, rare semileptonic, rare hadronic)
- Lepton-Universality-Violating observables
- Lepton-Flavor-Violating modes
- Lepton-Number-Violating modes

Strong suppression of these decays in the SM $\Rightarrow$ Smoking guns of NP

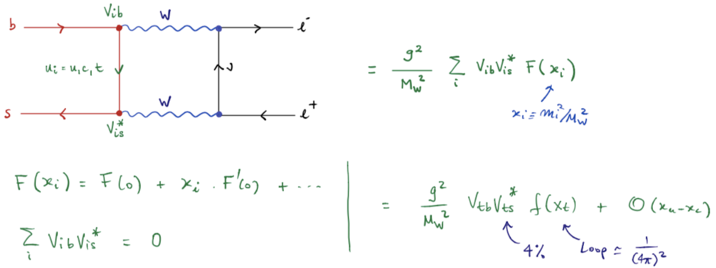
BUT: FCNCs are no longer "rare" at the LHC!

e.g. $N_{events}^{LHCb}(Run\,1) = 2398 \;\; ; N_{events}^{LHCb}(2016) = 2187$ for $B \to K^* \mu\mu$

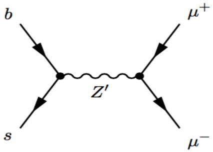
And will become "common" decays at **Belle-2** and **LHCb Upgrade II**.

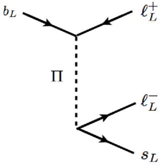
$\to$ Opportunity to study **BOTH** *New Physics* and *QCD* in rare decays.

SM is GIM/CKM and loop suppressed (and sometimes helicity):



Competes (potentially) with tree-level BSM contributions...





B mesons mix and decay due to $\mathcal{L}_{Weak} + \mathcal{L}_{BSM?}$

For $m_B \ll M_W, M_{BSM}$ we use an EFT : $\mathcal{L}_{EFT} = \mathcal{L}_{QCD+QED} + \sum_i C_i\, \mathcal{O}_i$

Class	Flavour structure	Number of Ops.	Other flavours	ADM	Example process
Class I	$\bar{s}b\,\bar{s}b$	5+3	$\bar{d}b\,\bar{d}b$	$\hat{\gamma}_{\rm I}$	$B_q - \overline{B}_q$ mixing
Class II	$\bar{u}b\,\bar{\ell}\nu_{\ell'}$	$(2+3)\times 9$	$\bar{c}b\,\bar{\ell}\nu_{\ell'}$	$\hat{\gamma}_{\rm II}$	$\overline{B}_d \to \pi^+\mu^-\bar{\nu}$
Class III	$\bar{s}b\,\bar{u}c$	10+10	$\bar{s}b\,\bar{c}u$ $\bar{d}b\,\bar{u}c$ $\bar{d}b\,\bar{c}u$	$\hat{\gamma}_{\rm III}$	$B^- \to \overline{D}^0 K^-$
Class IV	$\bar{s}b\,\bar{s}d$	5+5	$\bar{d}b\,\bar{d}s$ $\bar{b}s\,\bar{b}d$	$\hat{\gamma}_{\rm IV}$	$B^- \to \overline{K}^0 K^-$
Class V	$\bar{s}b\,\bar{q}q$ $\bar{s}b\,F$, $\bar{s}b\,G$ $\bar{s}b\,\bar{\ell}\ell$	57+57	$\bar{d}b\,\bar{q}q$ $\bar{d}b\,F$, $\bar{d}b\,G$ $\bar{d}b\,\bar{\ell}\ell$	$\hat{\gamma}_{\rm V}$	$\overline{B}_d \to D^+D_s^-$ $\overline{B}_d \to X_s\gamma$ $B^- \to K^-\mu^+\mu^-$
Class Vb	$\bar{s}b\,\bar{\ell}\ell'$, $\ell \neq \ell'$	$(5+5)\times 6$	$\bar{d}b\,\bar{\ell}\ell'$	$\hat{\gamma}_{\rm Vb}$	$\overline{B}_s \to \mu^-\tau^+$
Class Vν	$\bar{s}b\,\bar{\nu}_\ell\nu_{\ell'}$	$(1+1)\times 9$	$\bar{d}b\,\bar{\nu}_\ell\nu_{\ell'}$	zero	$B^- \to K^-\bar{\nu}\nu$

Aebischer, Fael, Greub, Virto 2017

Relevant part of the $\text{W}_{\text{eak}}\text{E}_{\text{ffective}}\text{T}_{\text{theory}}$ for $b \to s\ell\ell$ transitions:

$$\mathcal{L}_W = \mathcal{L}_{\rm QCD} + \mathcal{L}_{\rm QED} + \frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^\star \sum_i \mathcal{C}_i(\mu)\, \mathcal{O}_i(\mu)$$

$$\mathcal{O}_1 = (\bar{c}\gamma_\mu P_L b)(\bar{s}\gamma^\mu P_L c) \qquad \mathcal{O}_2 = (\bar{c}\gamma_\mu P_L T^a b)(\bar{s}\gamma^\mu P_L T^a c)$$

$$\mathcal{O}_7 = \frac{e}{16\pi^2} m_b (\bar{s}\sigma_{\mu\nu} P_R b) F^{\mu\nu} \qquad \mathcal{O}_{7'} = \frac{e}{16\pi^2} m_b (\bar{s}\sigma_{\mu\nu} P_L b) F^{\mu\nu}$$

$$\mathcal{O}_{9\ell} = \frac{\alpha}{4\pi} (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell) \qquad \mathcal{O}_{9'\ell} = \frac{\alpha}{4\pi} (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \ell)$$

$$\mathcal{O}_{10\ell} = \frac{\alpha}{4\pi} (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell) \qquad \mathcal{O}_{10'\ell} = \frac{\alpha}{4\pi} (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \gamma_5 \ell),$$

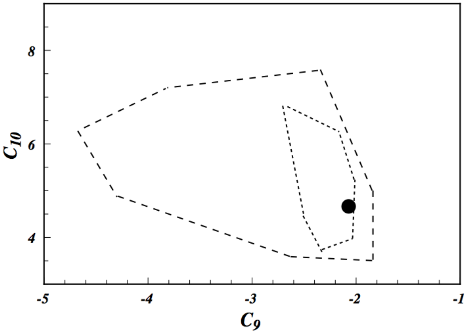
Currently, global determinations of $\mathcal{C}_9$ (and -maybe- $\mathcal{C}_{10}$) seem discrepant with SM predictions, with an important statistical significance.

How did we get here?

(a historical digression)

Fits to $b \to s$ transitions is not a new business

"Towards a Model-Independent Analysis of Rare B Decays", Ali, Giudice, Mannel, 1994

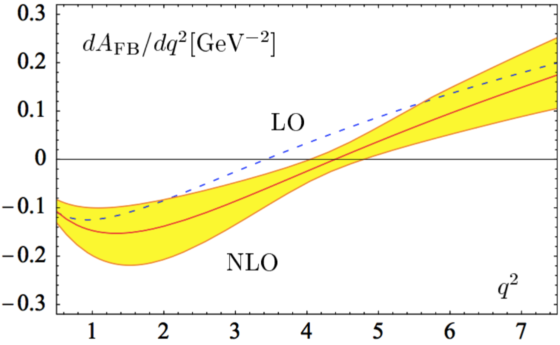


But measurements of key modes ($B_s \to \mu\mu$, $B \to K^{(*)}\ell\ell$) awaited LHC(b)

These measurements were anticipated by theorists.

Clean observables: A_{FB} zero

Beneke, Feldmann, Seidel 2001



Cancellation of hadronic uncertainties in the zero-crossing

At LO: $C_9 + \text{Re}(Y(q_0^2)) = -\dfrac{2M_B m_b}{q_0^2} C_7^{\text{eff}}$

Hadronic Form Factors at Large Recoil

Charles et al 1998; Beneke, Feldmann 2000

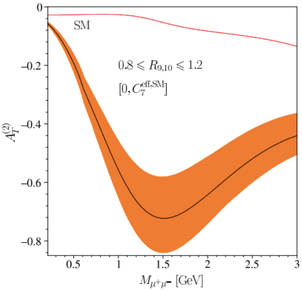
$$
\begin{aligned}
V(q^2) &= \frac{m_B + m_{K*}}{m_B}\,\xi_\perp(q^2) \;+\; \Delta V^{\alpha_s}(q^2) + \Delta V^{\Lambda}(q^2)\,,\\
A_1(q^2) &= \frac{2E}{m_B + m_{K*}}\,\xi_\perp(q^2) + \Delta A_1^{\alpha_s}(q^2) + \Delta A_1^{\Lambda}(q^2)\,,\\
A_2(q^2) &= \frac{m_B}{m_B - m_{K*}}\left[\xi_\perp(q^2) - \xi_\parallel(q^2)\right] + \Delta A_2^{\alpha_s}(q^2) + \Delta A_2^{\Lambda}(q^2)\,,\\
A_0(q^2) &= \frac{E}{m_{K*}}\,\xi_\parallel(q^2) + \Delta A_0^{\alpha_s}(q^2) + \Delta A_0^{\Lambda}(q^2)\,,\\
T_1(q^2) &= \xi_\perp(q^2) \;+\; \Delta T_1^{\alpha_s}(q^2) + \Delta T_1^{\Lambda}(q^2)\,,\\
T_2(q^2) &= \frac{2E}{m_B}\,\xi_\perp(q^2) + \Delta T_2^{\alpha_s}(q^2) + \Delta T_2^{\Lambda}(q^2)\,,\\
T_3(q^2) &= \left[\xi_\perp(q^2) - \xi_\parallel(q^2)\right] + \Delta T_3^{\alpha_s}(q^2) + \Delta T_3^{\Lambda}(q^2)\,,
\end{aligned}
$$

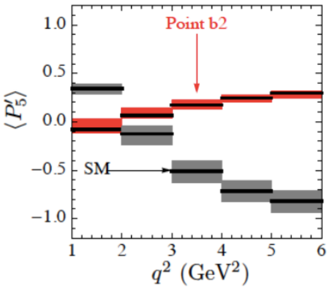
Only two independent structures at leading order + power

Clean observables for all q^2 (Cancellation as functions of q^2)

Kruger,Matias 2002

Descotes-Genon, Matias, Ramon, Virto 2012

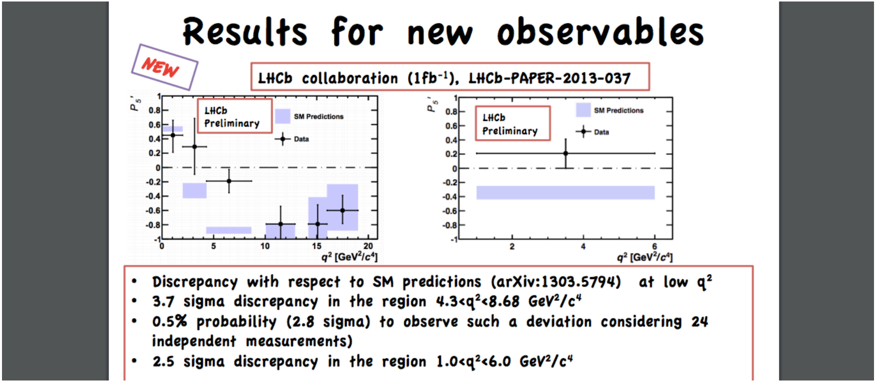




Also: clean observables at large q^2 Bobeth, Hiller, van Dyk

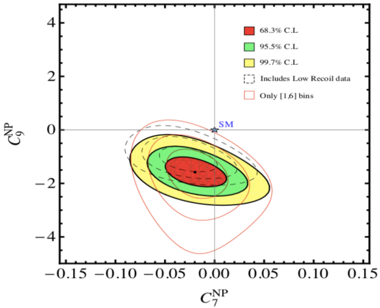
Full basis of "all-q^2-clean" observables Descotes-Genon, Hurth, Matias, Virto 2013

LHCb 2013 (2 papers)



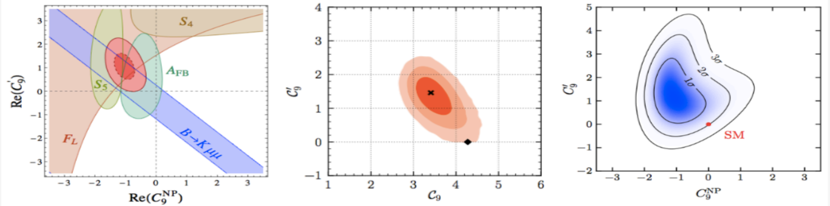
N. Serra, talk at EPS-HEP 2013

Descotes-Genon, Matias, Virto 2013



Indication for $\mathcal{C}_9^{\rm NP} \sim -1$

We have combined the recent LHCb measurements of $B \to K^* \mu^+ \mu^-$ observables [19, 20] with other radiative modes in a fit to Wilson coefficients, using the framework of our previous works [15, 21]. We have found a strong indication for a negative NP contribution to the coefficient $\mathcal{C}_9$, at $4.5\,\sigma$ using large-recoil data ($3.9\,\sigma$ using both large- and low-recoil data). Our results correspond to $\mathcal{C}_9$ inside a 68 % C.L. range $2.2 \le \mathcal{C}_9 \le 2.8$ to be compared with $\mathcal{C}_9^{\rm SM} = 4.07$ at the scale $\mu_b = 4.8$ GeV. This is the main conclusion of our analysis of LHCb $B \to K^* \mu^+ \mu^-$ measurements.



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

A new “twist”: Lepton Flavor Non-Universality

$$R_K \equiv \frac{\mathcal{B}(B^+ \to K^+ \mu\mu)_{[1,6]\text{GeV}^2}}{\mathcal{B}(B^+ \to K^+ ee)_{[1,6]\text{GeV}^2}}; \quad R_K^{\text{SM}} = 1; \quad R_K^{\text{LHCb 2014}} \simeq 0.75 \pm 0.1$$

Hiller,Kruger 2004; Bobeth, Hiller, Piranishvili 2007; Bordone, Isidori, Pattori 2016; LHCb 2014

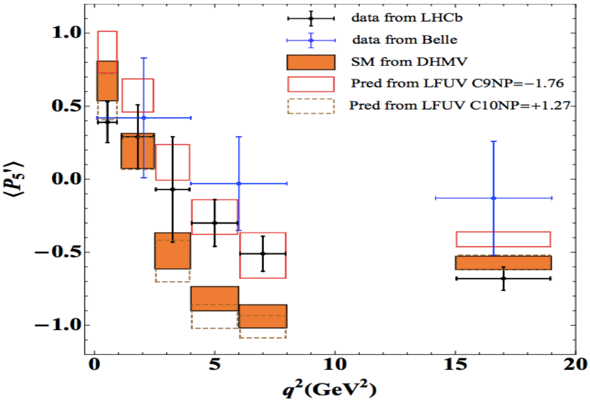
not very well bound, especially for the electronic case, so different scenarios of NP could currently explain (15). For example one could entertain the possibility of a sizable and negative effect in C_9 affecting only the muonic mode, $\delta C_9^\mu = -1$. In this scenario one obtains $R_K \simeq 0.79$. As a side remark, it is worth emphasizing that such a negative NP contribution to $\mathcal{O}_9^{(\prime)}$ has been argued to be necessary to understand the current $b \to s\mu\mu$ data set [27–30].

From Alonso, Grinstein, Camalich 2014

See also Hiller, Schmaltz 2014; Gosh, Nardecchia, Renner 2014

A new "twist": Lepton Flavor Non-Universality

Consistency of P_5' and LFNU in 2017 Capdevila, Crivellin, Descotes-Genon, Matias, Virto 2017



Fit to LFNU observables only (2017) predicted correct LHCb P_5' measurements

Current status of available measurements (2020)

Spectrum of available $b \to s\ell\ell$ Observables – (Total $= 180$)

$B_s \to \mu^+\mu^-$	$B \to X_s\mu^+\mu^-$	$B \to K^*\gamma$	$B \to X_s\gamma$
$B \to K\mu\mu$	$B \to K^*\mu\mu$	$B_s \to \Phi\mu\mu$	$\Lambda_b \to \Lambda\mu\mu$
BRs	AOs	Low q^2	Large q^2
R_K	R_{K^*}	LFU (μ)	LFUV (μ vs e)
LHCb	Belle/BaBar	ATLAS	CMS

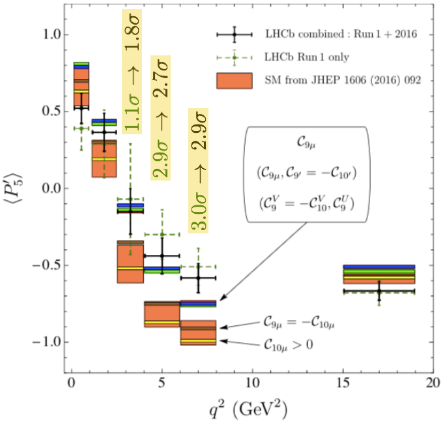
Latest updates: R_K^{LHCb}, R_K^{Belle} (2019), $B \to K^*\mu\mu$ (LHCb 2020 [Run 1 + 2016]).

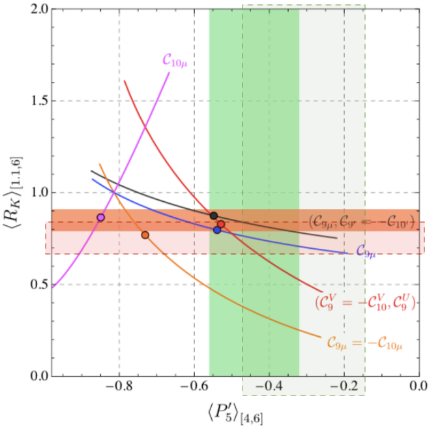
“Anomalies” (as of 2020)

Observable	Experiment	SM prediction	pull
$R_K^{[1.1,6]}$	0.85 ± 0.06	1.00 ± 0.01	$+2.5\sigma$
$R_{K*}^{[0.045,1.1]}$	$0.66^{+0.11}_{-0.07}$	0.92 ± 0.02	$+2.3\sigma$
$R_{K*}^{[1.1,6]}$	$0.69^{+0.12}_{-0.08}$	1.00 ± 0.01	$+2.6\sigma$
$\langle P_5' \rangle_{[4,6]}$	-0.44 ± 0.12	-0.82 ± 0.08	-2.7σ
$\langle P_5' \rangle_{[6,8]}$	-0.58 ± 0.09	-0.94 ± 0.08	-2.9σ
$\mathcal{B}_{\phi\mu\mu}^{[2,5]}$	0.77 ± 0.14	1.55 ± 0.33	$+2.2\sigma$
$\mathcal{B}_{\phi\mu\mu}^{[5.8]}$	0.96 ± 0.15	1.88 ± 0.89	$+2.2\sigma$

Global fit should accommodate these deviations within all other measurements

A closer look at new measurements of R_K and P_5' (LHCb 2019, 2020)

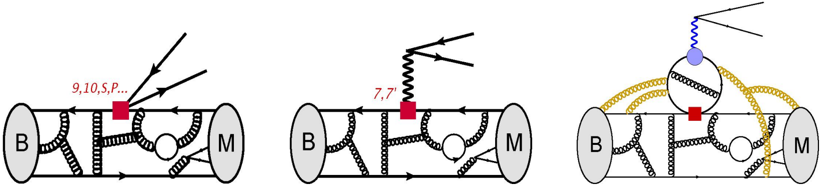




More details: Algeró et al. Addendum to Eur.Phys.J.C 79 (2019)

Some Details on Theory Predictions

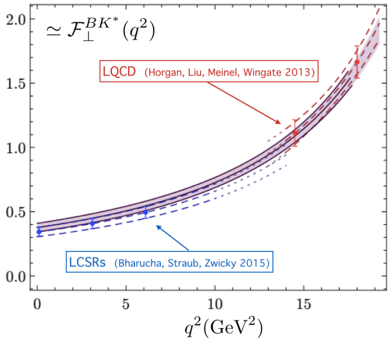
Anatomy of $B \to M_\lambda \ell^+\ell^-$ EFT Amplitudes

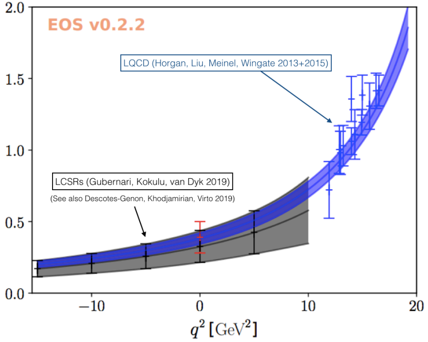


$$\mathcal{A}_\lambda^{L,R} = \mathcal{N}_\lambda \left\{ (C_9 \mp C_{10})\mathcal{F}_\lambda(q^2) + \frac{2m_b M_B}{q^2}\left[C_7 \mathcal{F}_\lambda^T(q^2) - 16\pi^2 \frac{M_B}{m_b}\mathcal{H}_\lambda(q^2)\right]\right\}$$

- Local (Form Factors) : $\mathcal{F}_\lambda^{(T)}(q^2) = \langle \bar{M}_\lambda(k)|\, \bar{s}\, \Gamma_\lambda^{(T)}\, b\, |\bar{B}(k+q)\rangle$
- Non-Local : $\mathcal{H}_\lambda(q^2) = i\,\mathcal{P}_\mu^\lambda \int d^4x\, e^{iq\cdot x} \langle \bar{M}_\lambda(k)|T\{\mathcal{J}^\mu_{\rm em}(x), \mathcal{C}_i\, \mathcal{O}_i(0)\}|\bar{B}(q+k)\rangle$

Local form factors





- Two main approaches: (1) Lattice QCD (large q^2) (2) LCSRs (low q^2)
- Two approaches to LCSRs, in terms of (1) K^* LCDAs (2) B LCDAs
- q^2 dependence can be parametrized model-independently

Non-local Form Factors: OPE + dispersion relations

$$\mathcal{H}_{\lambda,x}(q^2) = \mathcal{H}^{\rm OPE}_{\lambda,x}(q_0^2 < 0) + (q^2 - q_0^2)\int_{s_{\rm th}}^{\infty} dt\, \frac{\rho_{\lambda,x}(t)}{(t - q^2 - i\epsilon)(t - q_0^2)}$$

- $\mathcal{H}^{\rm OPE}_{\lambda,x}(q_0^2)$: Theory — e.g. Khodjamirian et al 2010, 2012; Asatrian, Greub, Virto 2019
- $\rho_{\lambda,c}(t)$: $B \to K^{(*)} J/\psi$, $B \to K^{(*)}\psi(2S)$, $B \to K^{(*)} D\bar{D}$, ...
- $\rho_{\lambda,sb}(t)$: $B \to K^{(*)}\phi$, $B \to K^{(*)}\bar{K}K$, ...
- $\rho_{\lambda,ud}(t)$: $B \to K^{(*)}\rho$, $B \to K^{(*)}\omega$, $B \to K^{(*)}\pi\pi$, $B \to K^{(*)}\pi\pi\pi$, ...

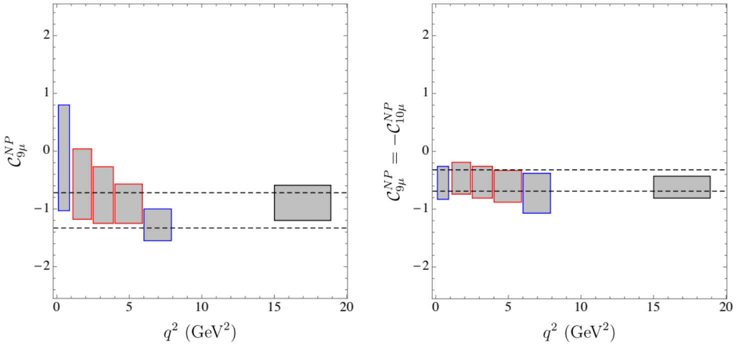
Charm contribution $\longrightarrow$ numerically leading

From OPE region to physical region requires DATA ($B \to K^{(*)} X_{1--}$)

$\Rightarrow$ Current fit uses QCDF (BFS) + KMPW correction + nuisances for PCs.

BFS = Beneke, Feldmann, Seidel 2001; KMPW = Khodjamirian et al 2010

Non-local Form Factors: Consistency Tests



Algeró et al. Addendum to Eur.Phys.J.C 79 (2019)

No evidence for a q^2 dependence pointing towards a missing LD effect, but interesting to see what happens with more and more precise data.

Updated Fits

Fit: Statistical Approach

$$\chi^2(C_i) = [O_{\rm exp} - O_{\rm th}(C_i)]_j \, [Cov^{-1}]_{jk} \, [O_{\rm exp} - O_{\rm th}(C_i)]_k$$

- $Cov = Cov^{\rm exp} + Cov^{\rm th}$
- $Cov^{\rm exp}$ is provided by LHCb
- Calculate $Cov^{\rm th}$: correlated multigaussian scan over all nuisance parameters
- $Cov^{\rm th}$ depends on C_i: Must check this dependence

For the Fit:

- Minimise $\chi^2 \to \chi^2_{\rm min} = \chi^2(C_i^0)$ (Best Fit Point = C_i^0)
- Confidence level regions: $\chi^2(C_i) - \chi^2_{\rm min} < \Delta\chi_{\sigma,n}$
- Compute pulls by inversion of the above formula

Some results of the fit: 1D

Algeró et al. Addendum to Eur.Phys.J.C 79 (2019)

	All				LFUV			
1D Hyp.	Best fit	$1\,\sigma/2\,\sigma$	Pull_{SM}	p-value	Best fit	$1\,\sigma/\,2\,\sigma$	Pull_{SM}	p-value
$\mathcal{C}_{9\mu}^{\text{NP}}$	-1.03	$[-1.19,-0.88]$ $[-1.33,-0.72]$	6.3	37.5 %	-0.91	$[-1.25,-0.61]$ $[-1.63,-0.34]$	3.3	60.7 %
$\mathcal{C}_{9\mu}^{\text{NP}}=-\mathcal{C}_{10\mu}^{\text{NP}}$	-0.50	$[-0.59,-0.41]$ $[-0.69,-0.32]$	5.8	25.3 %	-0.39	$[-0.50,-0.28]$ $[-0.62,-0.17]$	3.7	75.3 %
$\mathcal{C}_{9\mu}^{\text{NP}}=-\mathcal{C}_{9'\mu}$	-1.02	$[-1.17,-0.87]$ $[-1.31,-0.70]$	6.2	34.0 %	-1.67	$[-2.15,-1.05]$ $[-2.54,-0.48]$	3.1	53.1 %
$\mathcal{C}_{9\mu}^{\text{NP}}=-3\mathcal{C}_{9e}^{\text{NP}}$	-0.93	$[-1.08,-0.78]$ $[-1.23,-0.63]$	6.2	33.6 %	-0.68	$[-0.92,-0.46]$ $[-1.19,-0.25]$	3.3	60.8 %

TABLE VII. Most prominent 1D patterns of NP in $b\to s\mu^+\mu^-$ transitions (state-of-the-art fits as of March 2020). Here, Pull_{SM} is quoted in units of standard deviation and the p-value of the SM hypothesis is 1.4% for the fit "All" and 12.6% for the fit LFUV.

p-values have decreased in general due to decrease in experimental uncertainties

Some results of the fit: 6D

Algeró et al. Addendum to Eur.Phys.J.C 79 (2019)

	$\mathcal{C}_7^{\rm NP}$	$\mathcal{C}_{9\mu}^{\rm NP}$	$\mathcal{C}_{10\mu}^{\rm NP}$	$\mathcal{C}_{7'}$	$\mathcal{C}_{9'\mu}$	$\mathcal{C}_{10'\mu}$
Best fit	+0.00	-1.13	+0.20	+0.00	+0.49	-0.10
$1\ \sigma$	$[-0.02, +0.02]$	$[-1.30, -0.96]$	$[+0.05, +0.37]$	$[-0.01, +0.02]$	$[+0.04, +0.95]$	$[-0.33, +0.14]$
$2\ \sigma$	$[-0.03, +0.04]$	$[-1.46, -0.78]$	$[-0.09, +0.57]$	$[-0.03, +0.04]$	$[-0.39, +1.45]$	$[-0.55, +0.41]$

TABLE IX. 1 and 2σ confidence intervals for the NP contributions to Wilson coefficients in the 6D hypothesis allowing for NP in $b \to s\mu^+\mu^-$ operators dominant in the SM and their chirally-flipped counterparts, for the fit "All" (state-of-the-art as of March 2020). The Pull_{SM} is 5.8σ and the p-value is 46.8%.

$C_{9\mu}$ stands out since 2013

Some results of the fit: 2D

Algeró et al. Addendum to Eur.Phys.J.C 79 (2019)

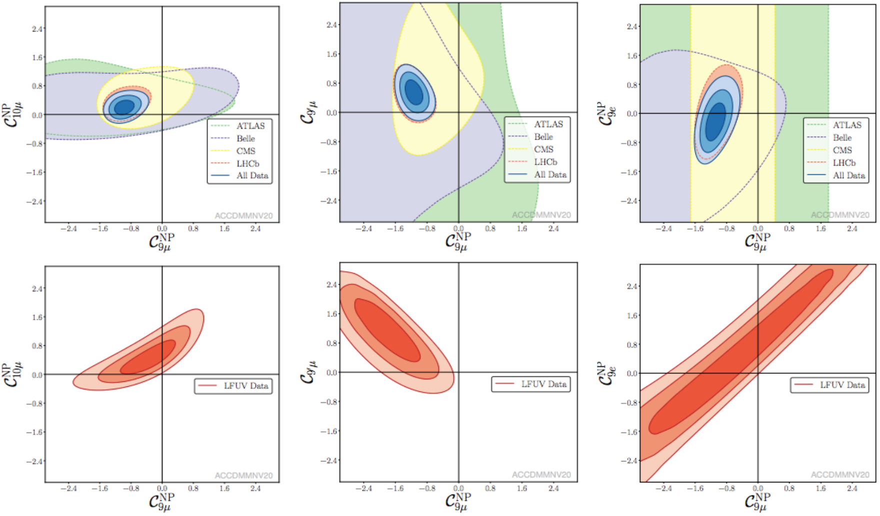
	All			LFUV		
2D Hyp.	Best fit	Pull_{SM}	p-value	Best fit	Pull_{SM}	p-value
$(\mathcal{C}_{9\mu}^{\text{NP}}, \mathcal{C}_{10\mu}^{\text{NP}})$	(-0.98,+0.19)	6.2	39.8 %	(-0.31,+0.44)	3.2	70.0 %
$(\mathcal{C}_{9\mu}^{\text{NP}}, \mathcal{C}_{7'})$	(-1.04,+0.01)	6.0	36.5 %	(-0.92,-0.04)	3.0	57.4 %
$(\mathcal{C}_{9\mu}^{\text{NP}}, \mathcal{C}_{9'\mu})$	(-1.14,+0.55)	6.5	47.4 %	(-1.86,+1.20)	3.5	81.2 %
$(\mathcal{C}_{9\mu}^{\text{NP}}, \mathcal{C}_{10'\mu})$	(-1.17,-0.33)	6.6	50.3 %	(-1.87,-0.59)	3.7	89.6 %
$(\mathcal{C}_{9\mu}^{\text{NP}}, \mathcal{C}_{9e}^{\text{NP}})$	(-1.09,-0.25)	6.0	36.5 %	(-0.72,+0.19)	2.9	54.5 %
Hyp. 1	(-1.10,+0.28)	6.5	48.9 %	(-1.69,+0.29)	3.5	82.4 %
Hyp. 2	(-1.01,+0.07)	5.9	33.7 %	(-1.95,+0.22)	3.1	64.3 %
Hyp. 3	(-0.51,+0.10)	5.4	24.0 %	(-0.39,-0.04)	3.2	69.9 %
Hyp. 4	(-0.52,+0.11)	5.6	26.4 %	(-0.46,+0.15)	3.4	77.9 %
Hyp. 5	(-1.17,+0.23)	6.6	51.1 %	(-2.05,+0.50)	3.8	91.9 %

TABLE VIII. Most prominent 2D patterns of NP in $b \to s\mu^+\mu^-$ transitions (state-of-the-art fits as of March 2020). The last five rows correspond to Hypothesis 1: $(\mathcal{C}_{9\mu}^{\text{NP}} = -\mathcal{C}_{9'\mu}, \mathcal{C}_{10\mu}^{\text{NP}} = \mathcal{C}_{10'\mu})$, 2: $(\mathcal{C}_{9\mu}^{\text{NP}} = -\mathcal{C}_{9'\mu}, \mathcal{C}_{10\mu}^{\text{NP}} = -\mathcal{C}_{10'\mu})$, 3: $(\mathcal{C}_{9\mu}^{\text{NP}} = -\mathcal{C}_{10\mu}^{\text{NP}}, \mathcal{C}_{9'\mu} = \mathcal{C}_{10'\mu})$, 4: $(\mathcal{C}_{9\mu}^{\text{NP}} = -\mathcal{C}_{10\mu}^{\text{NP}}, \mathcal{C}_{9'\mu} = -\mathcal{C}_{10'\mu})$ and 5: $(\mathcal{C}_{9\mu}^{\text{NP}}, \mathcal{C}_{9'\mu} = -\mathcal{C}_{10'\mu})$.

Several “good” scenarios, all featuring $C_{9\mu}$.

Some results of the fit: 2D

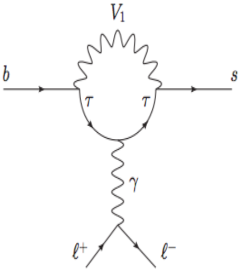
Algeró et al. Addendum to Eur.Phys.J.C 79 (2019)



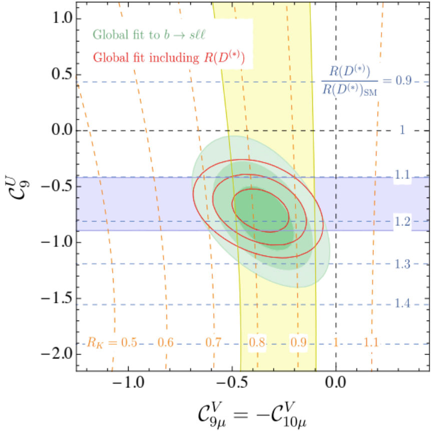
LHCb dominates de fits

Other interesting scenarios arise

Algeró et al. Addendum to Eur.Phys.J.C 79 (2019)



Crivellin, Greub, Müller, Saturnino

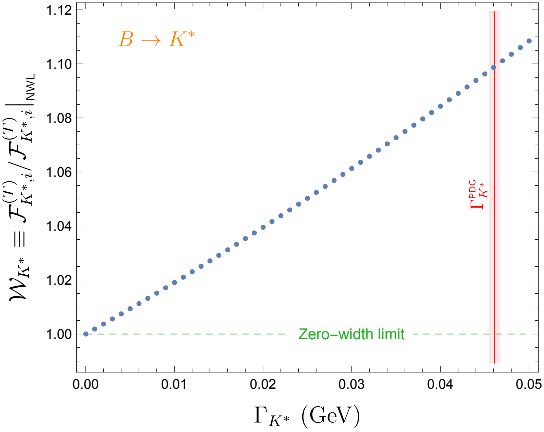


$b \to c$ anomaly induces $b \to s$ anomalies

Some future improvements

Form factors for unstable mesons (e.g., K^*): width effects

Descotes-Genon, Khodjamirian, Virto 2019



Crucial input: $\tau \to K\pi\nu$

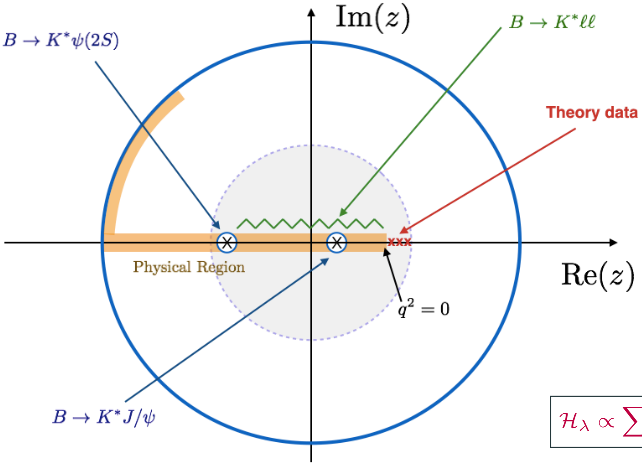
$$\mathcal{W}_{K^*} \simeq 1 + 1.9\,\frac{\Gamma_{K^*}}{m_{K^*}}$$

$$\mathcal{W}_{K^*} = 1.09 \pm 0.01$$

$\Rightarrow$ BRs are corrected by a factor $|\mathcal{W}_{K^*}|^2 \simeq 1.2$ (increasing anomalies)

Non-local Form Factors: analyticity

Bobeth, Chrzaszcz, van Dyk, Virto 1707.07305



$\mathcal{H}_\lambda \propto \sum \alpha_k z^k$

Constrain non-local effect with $B \to K^* \psi_n$ | Use interresonance $B \to K^* \ell\ell$ DATA

Non-local Form Factors: New OPE calculations of charm-loop effects

Gubernari, van Dyk, Virto, to appear

Results and comparison

$\Delta C9(q^2 = 1\,\mathrm{GeV}^2)$		KMPW2010	GvDV2019
factorizable contr.		0.27	0.27
$B \to K\ell\ell$	$\tilde{\mathcal{A}}$	$-0.09^{+0.06}_{-0.07}$	$(1.9^{+0.6}_{-0.6}) \cdot 10^{-4}$
$B \to K^*\ell\ell$	$\tilde{\mathcal{V}}_1$	$0.6^{+0.7}_{-0.5}$	$(1.2^{+0.4}_{-0.4}) \cdot 10^{-3}$
	$\tilde{\mathcal{V}}_2$	$0.6^{+0.7}_{-0.5}$	$(2.1^{+0.7}_{-0.7}) \cdot 10^{-3}$
	$\tilde{\mathcal{V}}_3$	$1.0^{+1.6}_{-0.8}$	$(3.0^{+1.0}_{-1.0}) \cdot 10^{-3}$

- results represented as a q^2 dependent correction to $C9$
- we reproduce the analytical results given in KMWP2010
- our results are two orders of magnitude smaller than in KMWP2010

Slide from N.Gubernari's PhD defense

Subleading contributions to non-local FFs might be much smaller than currently assumed!

Summary and comments:

- $b \to s\ell\ell$ anomalies are alive and in good shape after LHCb 2019/2020 analyses
- Despite psychological concerns, NP fit is good and SM pull is high
- Decrease of significance of certain tensions (e.g. R_K or P_5') might be good for NP
- A few different scenarios stand out. Consistent with 2013. Need more data to discern.

- Efforts on the QCD side less popular but terribly important
- Data-driven determination of hadronic effects promising and might be crucial
- In this context EXPERIMENT can also contribute immensely