Fits of a Lifetime

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Novel Aspects of $b \to s$ Transitions
Marseille – October 8, 2015

[In pleasant collaboration with
Sébastien, Lars and Quim]

Theoretishe Physik 1

UNIVERSITÄT SIEGEN

DFG FOR 1873

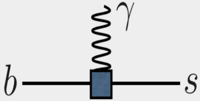
Rare $b \to s$ processes

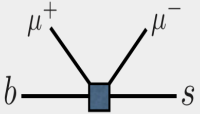
- Inclusive
  - $B \to X_s \gamma$ (BR)
  - $B \to X_s \ell^+ \ell^-$ (dBR/dq^2)
- Exclusive leptonic
  - $B_s \to \ell^+ \ell^-$ (BR)
- Exclusive radiative/semileptonic
  - $B \to K^* \gamma$ (BR, S, A_I)
  - $B \to K \ell^+ \ell^-$ (dBR/dq^2)
  - $B \to K^* \ell^+ \ell^-$ (dBR/dq^2, Angular Observables) $\to$ Huge set of observables!!
  - $B_s \to \phi \ell^+ \ell^-$ (dBR/dq^2, Angular Observables)
  - $\Lambda_b \to \Lambda \ell^+ \ell^-$ (None so far)
  - etc.

EFT at $\mu = m_b$ and $b \to s$ transitions

Radiative and Dileptonic $b \to s$ Operators

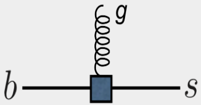
$$\mathcal{O}_{7(')} = [\bar{s}\sigma^{\mu\nu} P_{R(L)} b] F_{\mu\nu}$$
$$\mathcal{O}_{9(')} = [\bar{s}\gamma^{\mu} P_{L(R)} b][\bar{\ell}\gamma_{\mu}\ell]$$
$$\mathcal{O}_{10(')} = [\bar{s}\gamma^{\mu} P_{L(R)} b][\bar{\ell}\gamma_{\mu}\gamma_5\ell]$$
$$\mathcal{O}_{S(')}, \mathcal{O}_{P(')}, \mathcal{O}_{T,T5}$$

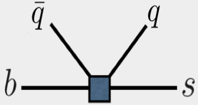




Hadronic $b \to s$ Operators

$$\mathcal{O}_{1} = [\bar{s}\gamma^{\mu} P_L c][\bar{c}\gamma_{\mu} P_L b]$$
$$\mathcal{O}_{3(5)} = [\bar{s}\gamma^{\mu} P_L b] \textstyle\sum_q [\bar{q}\gamma_{\mu} P_{L(R)} q]$$
$$\mathcal{O}_{8g} = [\bar{s}\sigma^{\mu\nu} P_{R(L)} T^a b] G^a_{\mu\nu}$$





($\mathcal{O}_{2,4,6} \sim \mathcal{O}_{1,3,5}$ with mixed color indices)

Effective Hamiltonian

$$\mathcal{H}_{\rm eff} = -\frac{4 G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left[\sum_{7,7',9,9',10,10'} \mathcal{C}_i \mathcal{O}_i + \sum_{1,\ldots,6,8g} \mathcal{C}_i \mathcal{O}_i \right]$$

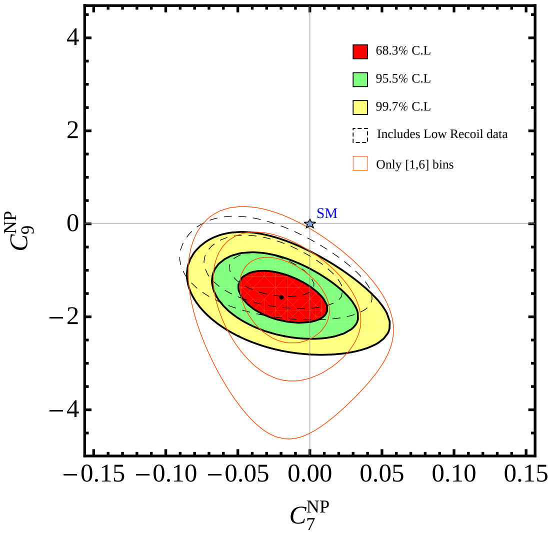
$$\mathcal{C}_{7\rm eff}^{\rm SM} = -0.3,\ \mathcal{C}_9^{\rm SM} = 4.1,\ \mathcal{C}_{10}^{\rm SM} = -4.3,\ \mathcal{C}_1^{\rm SM} = 1.1,\ \mathcal{C}_2^{\rm SM} = -0.4,\ \mathcal{C}_{\rm rest}^{\rm SM} \lesssim 10^{-2}$$

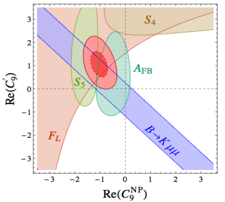
Rare $b \to s$ processes

- Inclusive
  - $B \to X_s\gamma$ (BR) .... $\mathcal{C}_7^{(\prime)}$, $\mathcal{C}_{\rm had}$
  - $B \to X_s\ell^+\ell^-$ (dBR/dq^2) .... $\mathcal{C}_7^{(\prime)}$, $\mathcal{C}_9^{(\prime)}$, $\mathcal{C}_{10}^{(\prime)}$, $\mathcal{C}_{\rm had}$
- Exclusive leptonic
  - $B_s \to \ell^+\ell^-$ (BR) .... $\mathcal{C}_{10}^{(\prime)}$
- Exclusive radiative/semileptonic
  - $B \to K^*\gamma$ (BR, S, A_I) .... $\mathcal{C}_7^{(\prime)}$, $\mathcal{C}_{\rm had}$
  - $B \to K\ell^+\ell^-$ (dBR/dq^2) .... $\mathcal{C}_7^{(\prime)}$, $\mathcal{C}_9^{(\prime)}$, $\mathcal{C}_{10}^{(\prime)}$, $\mathcal{C}_{\rm had}$
  - $B \to K^*\ell^+\ell^-$ (dBR/dq^2, Angular Observables) .... $\mathcal{C}_7^{(\prime)}$, $\mathcal{C}_9^{(\prime)}$, $\mathcal{C}_{10}^{(\prime)}$, $\mathcal{C}_{\rm had}$
  - $B_s \to \phi\ell^+\ell^-$ (dBR/dq^2, Angular Observables) .... $\mathcal{C}_7^{(\prime)}$, $\mathcal{C}_9^{(\prime)}$, $\mathcal{C}_{10}^{(\prime)}$, $\mathcal{C}_{\rm had}$
  - $\Lambda_b \to \Lambda\ell^+\ell^-$ (None so far)
  - etc.

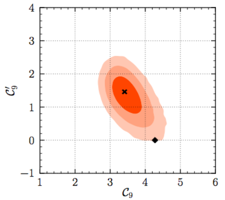
A bit of (pre)history

Descotes-Genon, Matias, JV 1307.5683

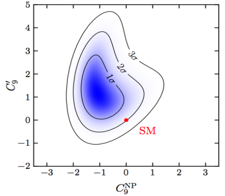




[Altmannshofer, Straub],



[Beaujean, Bobeth, van Dyk],



[Horgan et al.],

Updates for 2015 Fits

- $BR(B \to X_s \gamma)$
  - New theory update: $\mathcal{B}_{s\gamma}^{\rm SM} = (3.36 \pm 0.23) \cdot 10^{-4}$ (Misiak et al 2015)
  - $+6.4\%$ shift in central value w.r.t 2006 $\to$ excellent agreement with WA
- $BR(B_s \to \mu^+\mu^-)$
  - New theory update (Bobeth et al 2013), New LHCb+CMS average (2014)
- $BR(B \to X_s \mu^+\mu^-)$
  - New theory update (Huber et al 2015)
- $BR(B \to K \mu^+\mu^-)$:
  - LHCb 2014 + Lattice form factors at large q^2 (Bouchard et al 2013, 2015)
- $B_{(s)} \to (K^*, \phi)\mu^+\mu^-$: BRs & Angular Observables
  - LHCb 2015 + Lattice form factors at large q^2 (Horgan et al 2013)
- $BR(B \to K e^+ e^-)_{[1,6]}$ (or R_K) and $B \to K^* e^+ e^-$ at very low q^2
  - LHCb 2014, 2015

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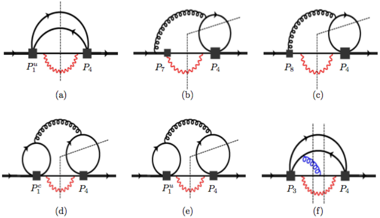
Quick merchardising:

Four-body contributions to $B \to X_s\gamma$ at NLO,
T.Huber, M.Poradzinski and JV
arXiv:1411.7677 [hep-ph] – JHEP



Updated NNLO QCD predictions for the Weak Radiative B-meson decays,
M. Misiak, H. M. Asatrian, R. Boughezal, M. Czakon, T. Ewerth, A. Ferroglia, P. Fiedler, P. Gambino, C. Greub, U. Haisch, T. Huber, M. Kamiński, G. Ossola, M. Poradziński, A. Rehman, T. Schutzmeier, M. Steinhauser, and JV
arXiv:1503.03328 [hep-ph] – PRL

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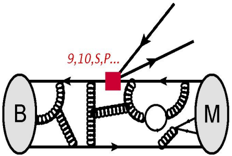
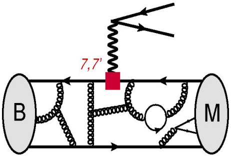
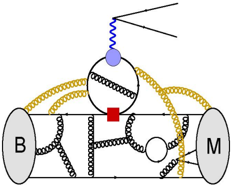
  - LHCb 2014, 2015

Comments on $B \to V\ell\ell$

Amplitudes: $B \to V\gamma,\ B \to M\ell^+\ell^-$







$$\mathcal{M} \;=\; \frac{G_F\alpha}{\sqrt{2}\pi} V_{tb}V_{ts}^* \left[(\mathcal{A}_\mu + \mathcal{T}_\mu)\ \bar{u}_\ell \gamma^\mu v_\ell + \mathcal{B}_\mu\ \bar{u}_\ell\gamma^\mu\gamma_5 v_\ell \right]$$

Local:

$$\mathcal{A}_\mu \;=\; -\frac{2m_b q^\nu}{q^2}\mathcal{C}_7 \langle M_\lambda|\bar{s}\sigma_{\mu\nu}P_R b|B\rangle + \mathcal{C}_9 \langle M_\lambda|\bar{s}\gamma_\mu P_L b|B\rangle$$

$$\mathcal{B}_\mu \;=\; \mathcal{C}_{10}\ \langle M_\lambda|\bar{s}\gamma_\mu P_L b|B\rangle$$

Non-Local:

$$\mathcal{T}_\mu \;=\; -\frac{16 i\pi^2}{q^2} \sum_{i=1..6,8} \mathcal{C}_i \int dx^4 e^{iq\cdot x} \langle M_\lambda| T\{\mathcal{J}_\mu^{\rm em}(x)\mathcal{O}_i(0)\}|B\rangle$$

2 main issues:

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

$B \to K^*\ell\bar{\ell}$: Form Factors

Low q^2 ::

- Altmannshofer, Bharucha, Straub, Zwicky:

  LCSRs with K^* DAs + Correlations + EOM constraint

  q^2 dependence given by simplified z-expansion

- Descotes-Genon, Hofer, Matias, JV (DHMV):

  LCSRs with B DAs (uncorrelated) + SCET relations + Power corrections

  q^2 dependence given by simplified z-expansion

- Jäger + Camalich:

  Try to rely only on HQ/LE expansion, both for $q^2 = 0$ and q^2-dependence

  Input: LCSRs, DSE, $B \to K^*\gamma$, + power corrections

Large q^2 ::

- Horgan et al: Lattice QCD

$B \to K^*\ell\bar{\ell}$: Form Factors – DHMV

$$V(q^2) = \frac{m_B + m_{K^*}}{m_B}\,\xi_\perp(q^2) + \Delta V^{\alpha_s}(q^2) + \Delta V^{\Lambda}(q^2)\,,$$

$$A_1(q^2) = \frac{2E}{m_B + m_{K^*}}\,\xi_\perp(q^2) + \Delta A_1^{\alpha_s}(q^2) + \Delta A_1^{\Lambda}(q^2)\,,$$

$$A_2(q^2) = \frac{m_B}{m_B - m_{K^*}}\left[\xi_\perp(q^2) - \xi_\parallel(q^2)\right] + \Delta A_2^{\alpha_s}(q^2) + \Delta A_2^{\Lambda}(q^2)\,,$$

$$A_0(q^2) = \frac{E}{m_{K^*}}\,\xi_\parallel(q^2) + \Delta A_0^{\alpha_s}(q^2) + \Delta A_0^{\Lambda}(q^2)\,,$$

$$T_1(q^2) = \xi_\perp(q^2) + \Delta T_1^{\alpha_s}(q^2) + \Delta T_1^{\Lambda}(q^2)\,,$$

$$T_2(q^2) = \frac{2E}{m_B}\,\xi_\perp(q^2) + \Delta T_2^{\alpha_s}(q^2) + \Delta T_2^{\Lambda}(q^2)\,,$$

$$T_3(q^2) = \left[\xi_\perp(q^2) - \xi_\parallel(q^2)\right] + \Delta T_3^{\alpha_s}(q^2) + \Delta T_3^{\Lambda}(q^2)\,,$$

Fact. Power corrections: $\Delta F^{\Lambda}(q^2) = a_F + b_F\,\frac{q^2}{m_B^2} + c_F\,\frac{q^4}{m_B^4} + \ldots,$

$B \to K^* \ell \bar{\ell}$: h_i : Corrections to QCDF at low-q^2 – DHMV

$$\mathcal{T}_i^{\rm had} \to \big(1 + r_i(q^2)\big)\mathcal{T}_i^{\rm had},$$

$$r_i(s) = r_i^a e^{i\phi_i^a} + r_i^b e^{i\phi_i^b}(s/m_B^2) + r_i^c e^{i\phi_i^c}(s/m_B^2)^2.$$

With $r_i^{a,b,c} \in [0, 0.1]$ and $\phi_i^{a,b,c} \in [-\pi, \pi]$

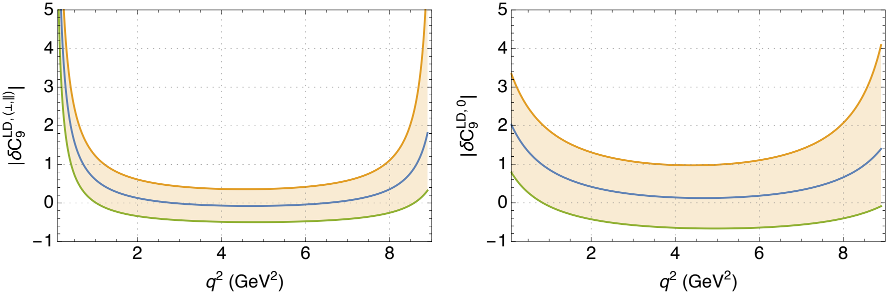
$B \to K^* \ell\bar{\ell}$: h_i : Charm – DHMV

Inspired by Khodjamirian et al (KMPW): $C_9 \to C_9 + s_i\ \delta C_9^{\mathrm{LD}(i)}(q^2)$

$$\delta C_9^{\mathrm{LD},(\perp,\|)}(q^2) = \frac{a^{(\perp,\|)} + b^{(\perp,\|)} q^2 [c^{(\perp,\|)} - q^2]}{b^{(\perp,\|)} q^2 [c^{(\perp,\|)} - q^2]}$$

$$\delta C_9^{\mathrm{LD},0}(q^2) = \frac{a^0 + b^0 [q^2 + s_0][c^0 - q^2]}{b^0 [q^2 + s_0][c^0 - q^2]}$$

We vary s_i independently in the range $[-1, 1]$ (only $s_i = 1$ in KMPW).



$B \to K^*\ell\bar{\ell}$: h_i : large-q^2 – DHMV

- OPE up to dimension 3 ops (Buchalla et al)
- NLO QCD corrections to the OPE coeffs (Greub et al)
- Lattice QCD form factors with correlations (Horgan et al proceeding update)
- $\pm 10\%$ by hand to account for possible Duality Violations

SM predictions and Pulls : $B \to K\mu\mu$

$BR(B^+ \to K^+\mu^+\mu^-)$	Standard Model	Experiment	Pull
$[0.1, 0.98]$	0.314 ± 0.092	0.292 ± 0.022	$+0.2$
$[1.1, 2]$	0.321 ± 0.100	0.210 ± 0.017	$+$ **1.1**
$[2, 3]$	0.354 ± 0.113	0.282 ± 0.021	$+0.6$
$[3, 4]$	0.351 ± 0.115	0.254 ± 0.020	$+0.8$
$[4, 5]$	0.348 ± 0.117	0.221 ± 0.018	$+$**1.1**
$[5, 6]$	0.345 ± 0.120	0.231 ± 0.018	$+0.9$
$[6, 7]$	0.343 ± 0.125	0.245 ± 0.018	$+0.8$
$[7, 8]$	0.343 ± 0.131	0.231 ± 0.018	$+0.8$
$[15, 22]$	0.975 ± 0.133	0.847 ± 0.049	$+0.9$
$BR(B^0 \to K^0\mu^+\mu^-)$	Standard Model	Experiment	Pull
$[0.1, 2]$	0.629 ± 0.191	0.232 ± 0.105	$+$**1.8**
$[2, 4]$	0.654 ± 0.211	0.374 ± 0.106	$+$**1.2**
$[4, 6]$	0.643 ± 0.221	0.346 ± 0.103	$+$**1.2**
$[6, 8]$	0.636 ± 0.237	0.540 ± 0.115	$+0.4$
$[15, 19]$	0.904 ± 0.124	0.665 ± 0.116	$+$**1.4**

SM predictions and Pulls : $BR(B \to V\mu\mu)$

$BR(B^0 \to K^{*0}\mu^+\mu^-)$	Standard Model	Experiment	Pull
$[0.1, 2]$	1.359 ± 1.075	1.140 ± 0.181	$+0.2$
$[2, 4.3]$	0.768 ± 0.523	0.690 ± 0.115	$+0.1$
$[4.3, 8.68]$	2.278 ± 1.776	2.146 ± 0.307	$+0.1$
$[16, 19]$	1.652 ± 0.152	1.230 ± 0.195	$+\mathbf{1.7}$
$BR(B^+ \to K^{*+}\mu^+\mu^-)$	Standard Model	Experiment	Pull
$[0.1, 2]$	1.405 ± 1.123	1.121 ± 0.266	$+0.2$
$[2, 4]$	0.723 ± 0.487	1.120 ± 0.320	-0.7
$[4, 6]$	0.856 ± 0.625	0.500 ± 0.200	$+0.5$
$[6, 8]$	1.054 ± 0.831	0.660 ± 0.220	$+0.5$
$[15, 19]$	2.586 ± 0.247	1.600 ± 0.320	$+\mathbf{2.4}$
$BR(B_s \to \phi\mu^+\mu^-)$	Standard Model	Experiment	Pull
$[0.1, 2.]$	1.880 ± 0.372	1.112 ± 0.161	$+\mathbf{1.9}$
$[2., 5.]$	1.702 ± 0.281	0.768 ± 0.135	$+\mathbf{3.0}$
$[5., 8.]$	2.024 ± 0.357	0.963 ± 0.150	$+\mathbf{2.7}$
$[15, 18.8]$	2.198 ± 0.167	1.616 ± 0.202	$+\mathbf{2.2}$

SM predictions and Pulls : $P_i(B \to K^* \mu\mu)$

$P_1(B \to K^* \mu^+ \mu^-)$	Standard Model	Experiment	Pull
[15, 19]	-0.643 ± 0.055	-0.497 ± 0.109	**−1.2**

$P_2(B \to K^* \mu^+ \mu^-)$	Standard Model	Experiment	Pull
[0.1, 0.98]	0.117 ± 0.016	0.003 ± 0.054	**+2.0**
[6, 8]	-0.371 ± 0.071	-0.241 ± 0.072	**−1.3**

$P_5'(B \to K^* \mu^+ \mu^-)$	Standard Model	Experiment	Pull
[0.1, 0.98]	0.676 ± 0.139	0.386 ± 0.144	**+1.4**
[2.5, 4]	-0.468 ± 0.122	-0.067 ± 0.338	**−1.1**
[4, 6]	-0.808 ± 0.082	-0.299 ± 0.160	**−2.8**
[6, 8]	-0.935 ± 0.078	-0.504 ± 0.128	**−2.9**
[15, 19]	-0.574 ± 0.047	-0.684 ± 0.083	**+1.2**

$P_6'(B \to K^* \mu^+ \mu^-)$	Standard Model	Experiment	Pull
[1.1, 2.5]	-0.073 ± 0.028	0.462 ± 0.225	**−2.4**

$P_8'(B \to K^* \mu^+ \mu^-)$	Standard Model	Experiment	Pull
[0.1, 0.98]	0.021 ± 0.025	0.359 ± 0.354	**−1.0**
[4, 6]	0.031 ± 0.019	0.685 ± 0.399	**−1.6**
[6, 8]	0.018 ± 0.012	-0.344 ± 0.297	**+1.2**

SM predictions and Pulls : $P_i(B_s \to \Phi\mu\mu)$

$P_1(B_s \to \phi\mu^+\mu^-)$	Standard Model	Experiment	Pull
$[15, 18.8]$	-0.689 ± 0.033	-0.253 ± 0.341	**-1.3**

$P_4'(B_s \to \phi\mu^+\mu^-)$	Standard Model	Experiment	Pull
$[15, 18.8]$	1.296 ± 0.014	0.617 ± 0.486	**$+1.4$**

$P_6'(B_s \to \phi\mu^+\mu^-)$	Standard Model	Experiment	Pull
$[15, 18.8]$	-0.003 ± 0.072	-0.286 ± 0.243	**$+1.1$**

$F_L(B_s \to \phi\mu^+\mu^-)$	Standard Model	Experiment	Pull
$[0.1, 2.]$	0.431 ± 0.081	0.200 ± 0.087	**$+2.0$**
$[5., 8.]$	0.655 ± 0.048	0.540 ± 0.097	**$+1.0$**
$[15, 18.8]$	0.356 ± 0.023	0.290 ± 0.068	$+0.9$

Fit: Statistical Approach

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

- $Cov = Cov^{\text{exp}} + Cov^{\text{th}}$
- We have Cov^{exp} for the first time
- Calculate Cov^{th}: correlated multigaussian scan over all nuisance parameters
- Cov^{th} depends on C_i: Must check this dependence

For the Fit:

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

Fits

All include $B \to X_s\gamma$, $B \to K^*\gamma$, $B_s \to \mu^+\mu^-$, $B \to X_s\mu^+\mu^-$ by default.

- **Fit 1 (Canonical):** $B_{(s)} \to (K^{(*)}, \phi)\mu^+\mu^-$, **$BR$'s and P_i's, All q^2** (91 obs)

- **Fit 2**: Branching Ratios only (27 obs)
- **Fit 3**: P_i Angular Observables only (64 obs)
- **Fit 4**: S_i Angular Observables only (64 obs)

- **Fit 5**: $B \to K\mu^+\mu^-$ only (14 obs)
- **Fit 6**: $B \to K^*\mu^+\mu^-$ only (57 obs)
- **Fit 7**: $B_s \to \phi\mu^+\mu^-$ only (20 obs)

- **Fit 8**: Large Recoil only (74 obs)
- **Fit 9**: Low Recoil only (17 obs)
- **Fit 10**: Only bins within [1,6] GeV^2 (39 obs)
- **Fits 11**: Bin-by-bin analysis.

- **Fit 12**: Full form factor approach [a la ABSZ] (91 obs)
- **Fit 13**: Enhanced Power Corrections (91 obs)
- **Fit 14**: Enhanced Charm loop effect (91 obs)

Fit 1: 1D fits

Coefficient	Best fit	1σ	3σ	Pull_{SM}
$\mathcal{C}_7^{\text{NP}}$	-0.02	$[-0.04, -0.00]$	$[-0.07, 0.04]$	1.0
$\boldsymbol{\mathcal{C}_9^{\text{NP}}}$	-1.13	$[-1.33, -0.91]$	$[-1.72, -0.42]$	**4.6**
$\mathcal{C}_{10}^{\text{NP}}$	0.47	$[0.21, 0.74]$	$[-0.28, 1.35]$	1.8
$\mathcal{C}_{7'}^{\text{NP}}$	0.02	$[-0.01, 0.04]$	$[-0.06, 0.09]$	0.7
$\mathcal{C}_{9'}^{\text{NP}}$	0.48	$[0.19, 0.77]$	$[-0.36, 1.37]$	1.7
$\mathcal{C}_{10'}^{\text{NP}}$	-0.24	$[-0.45, -0.04]$	$[-0.87, 0.38]$	1.2
$\mathcal{C}_9^{\text{NP}} = \mathcal{C}_{10}^{\text{NP}}$	-0.42	$[-0.61, -0.23]$	$[-0.94, 0.25]$	2.0
$\boldsymbol{\mathcal{C}_9^{\text{NP}} = -\mathcal{C}_{10}^{\text{NP}}}$	-0.70	$[-0.89, -0.50]$	$[-1.30, -0.15]$	**3.9**
$\mathcal{C}_{9'}^{\text{NP}} = \mathcal{C}_{10'}^{\text{NP}}$	0.04	$[-0.28, 0.35]$	$[-0.91, 0.97]$	0.1
$\mathcal{C}_{9'}^{\text{NP}} = -\mathcal{C}_{10'}^{\text{NP}}$	0.19	$[0.06, 0.32]$	$[-0.19, 0.57]$	1.5
$\boldsymbol{\mathcal{C}_9^{\text{NP}} = -\mathcal{C}_{9'}^{\text{NP}}}$	-1.09	$[-1.28, -0.88]$	$[-1.62, -0.42]$	**4.8**

Fit 1: 1D $\to$ 2D fits

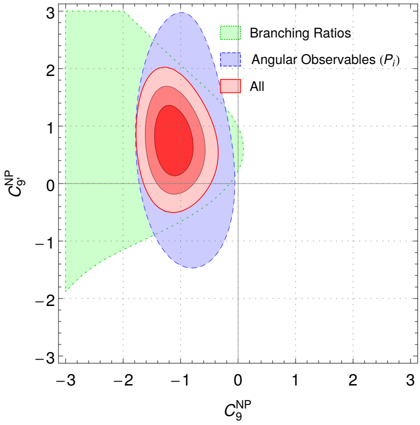
	$\mathcal{C}_7^{\rm NP}$	$\mathcal{C}_9^{\rm NP}$	$\mathcal{C}_{10}^{\rm NP}$	$\mathcal{C}_{7'}^{\rm NP}$	$\mathcal{C}_{9'}^{\rm NP}$	$\mathcal{C}_{10'}^{\rm NP}$
	1.02	**4.56**	1.84	0.74	1.68	1.17
$\mathcal{C}_7^{\rm NP}$	*	0.10	0.74	0.99	1.02	1.00
$\mathcal{C}_9^{\rm NP}$	**4.44**	*	**4.27**	**4.61**	**4.64**	**4.75**
$\mathcal{C}_{10}^{\rm NP}$	1.70	0.94	*	1.74	1.38	1.48
$\mathcal{C}_{7'}^{\rm NP}$	0.70	1.00	0.44	*	0.47	0.46
$\mathcal{C}_{9'}^{\rm NP}$	1.69	1.91	1.16	1.58	*	1.21
$\mathcal{C}_{10'}^{\rm NP}$	1.16	1.78	0.43	1.02	0.12	*

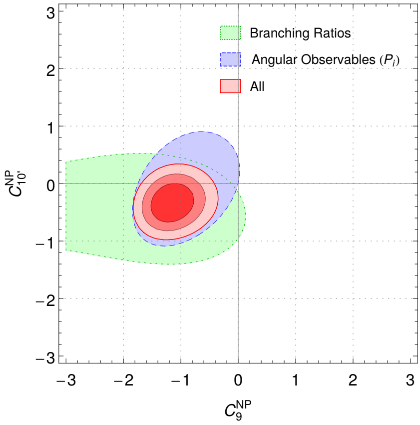
Fit 1: 2D fits :: only scenarios with $\text{Pull}_{\text{SM}} > 4$

Coefficient	Best Fit Point	Pull_{SM}
$(\mathcal{C}_7^{\text{NP}}, \mathcal{C}_9^{\text{NP}})$	$(+0.00, -1.14)$	4.2
$(\mathcal{C}_9^{\text{NP}}, \mathcal{C}_{10}^{\text{NP}})$	$(-1.15, +0.20)$	4.3
$(\mathcal{C}_9^{\text{NP}}, \mathcal{C}_{7'}^{\text{NP}})$	$(-1.15, +0.02)$	4.3
$(\mathcal{C}_9^{\text{NP}}, \mathcal{C}_{9'}^{\text{NP}})$	$(-1.17, +0.70)$	**4.6**
$(\mathcal{C}_9^{\text{NP}}, \mathcal{C}_{10'}^{\text{NP}})$	$(-1.21, -0.35)$	**4.5**
$(\mathcal{C}_9^{\text{NP}} = -\mathcal{C}_{9'}^{\text{NP}}, \mathcal{C}_{10}^{\text{NP}} = \mathcal{C}_{10'}^{\text{NP}})$	$(-1.16, +0.21)$	**4.6**
$(\mathcal{C}_9^{\text{NP}} = -\mathcal{C}_{9'}^{\text{NP}}, \mathcal{C}_{10}^{\text{NP}} = -\mathcal{C}_{10'}^{\text{NP}})$	$(-1.09, -0.03)$	**4.5**

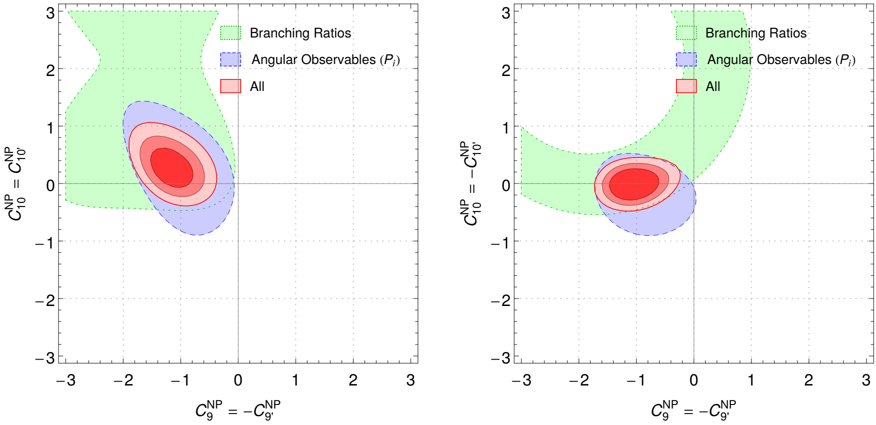
RUTHLESS BATTERY OF PLOTS

Branching Ratios vs. Angular Observables

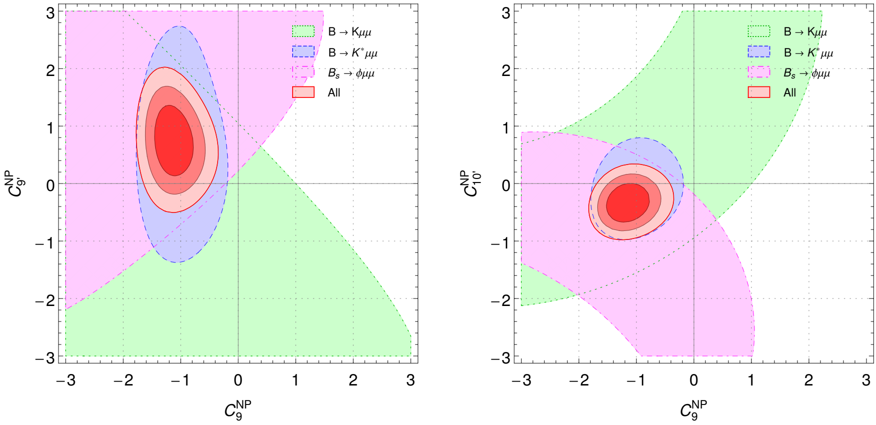




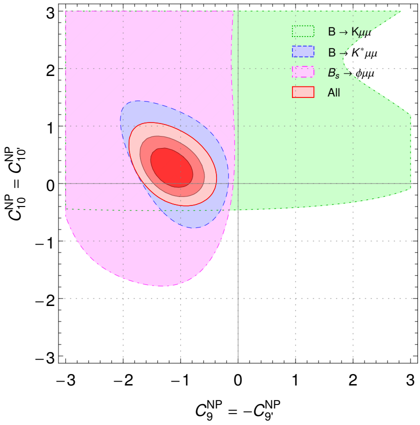
Branching Ratios vs. Angular Observables

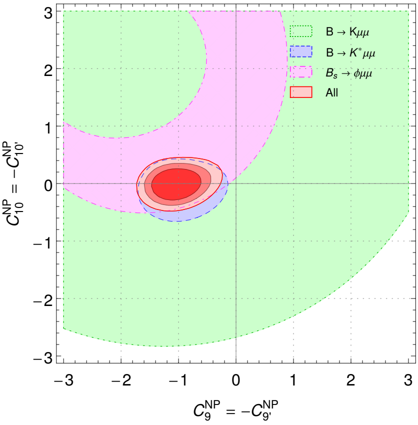


$B \to K\mu\mu$ vs. $B \to K^*\mu\mu$ vs. $B_s \to \phi\mu\mu$

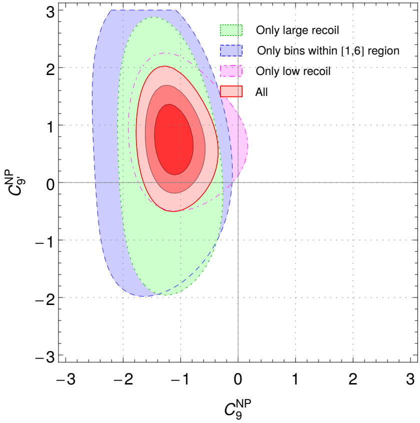


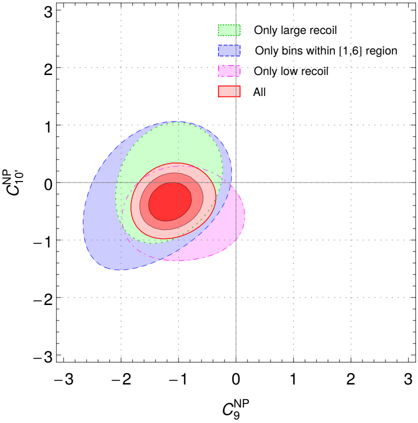
$B \to K\mu\mu$ vs. $B \to K^*\mu\mu$ vs. $B_s \to \phi\mu\mu$



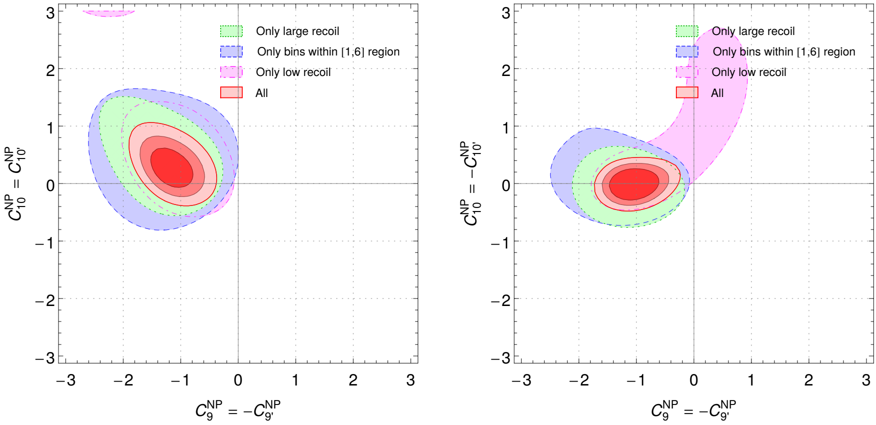


Different q^2 regions

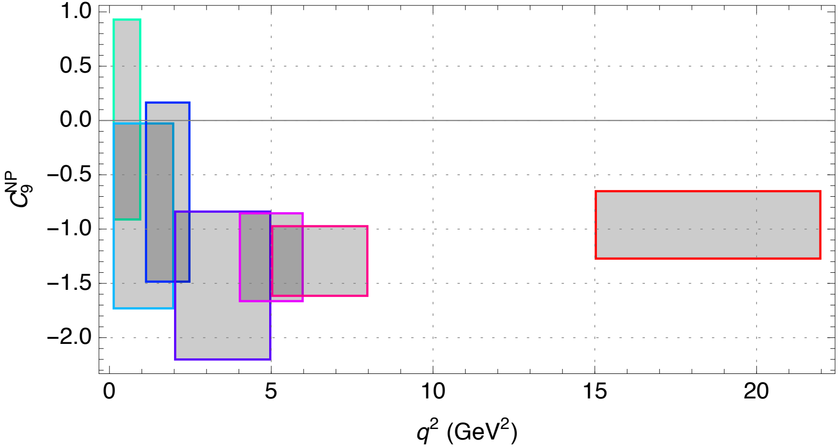




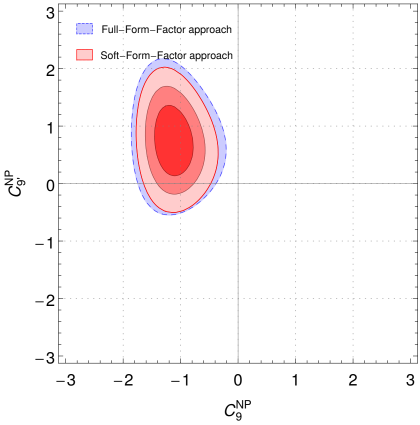
Different q^2 regions

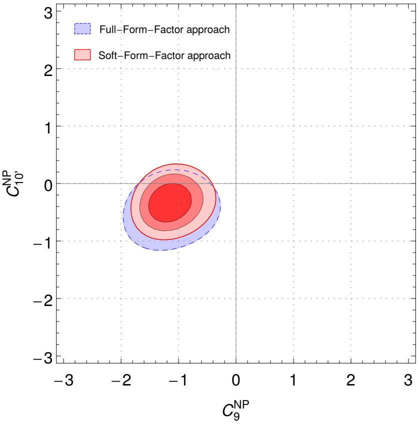


Different q^2 regions

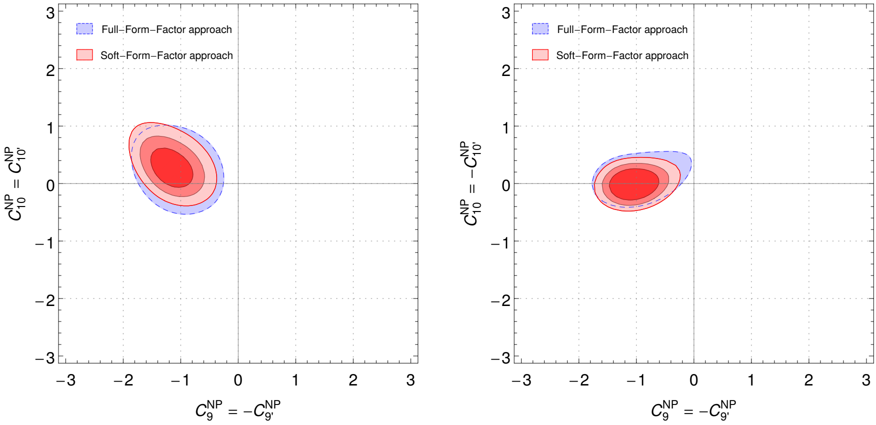


DHMV vs. Full form factors

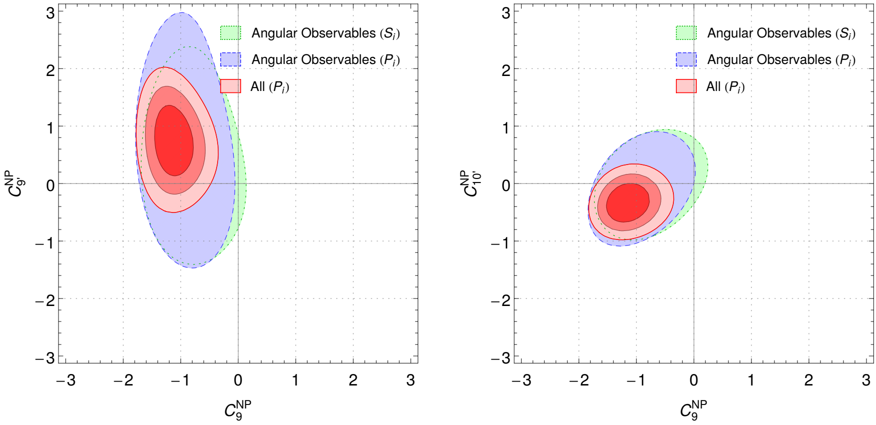




DHMV vs. Full form factors

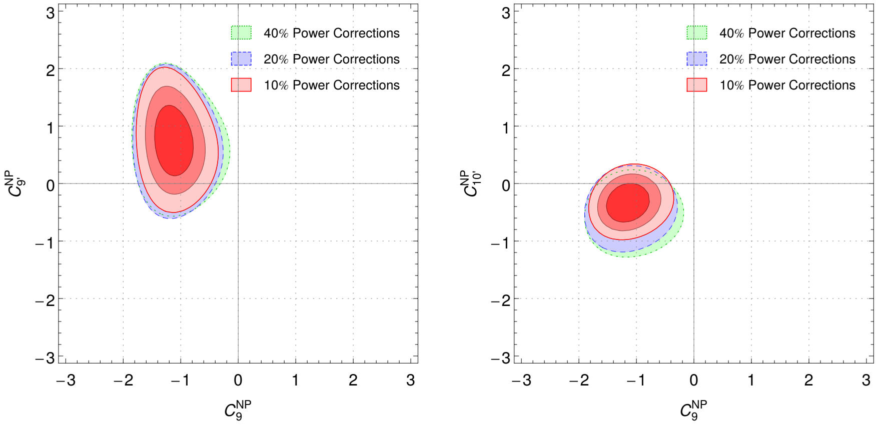


P_i's vs. S_i's

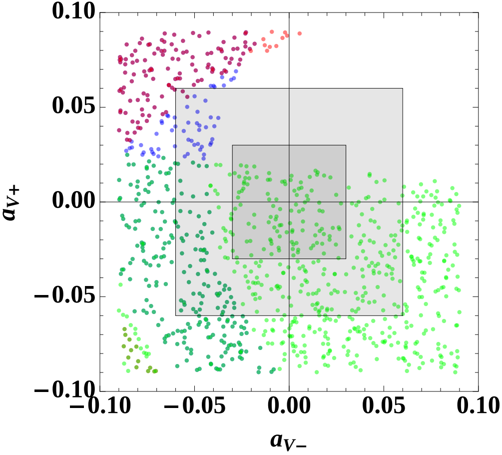


Angular Observables (S_i)
Angular Observables (P_i)
All (P_i)
$C_{9'}^{NP}$
C_9^{NP}
3
2
1
0
−1
−2
−3
Angular Observables (S_i)
Angular Observables (P_i)
All (P_i)
$C_{10'}^{NP}$
C_9^{NP}

Enhanced Power Corrections

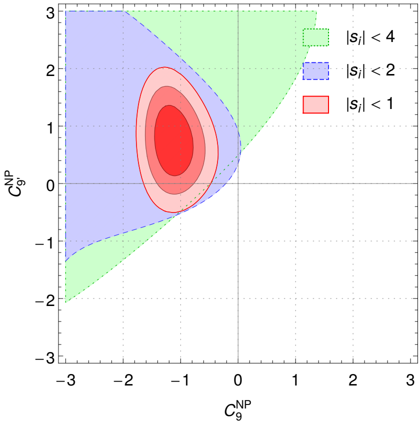


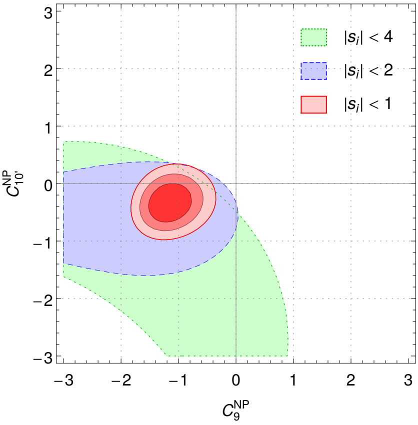
Enhanced Power Corrections



$\langle P_1 \rangle_{[4,6]}$, $\langle P_2 \rangle_{[4,6]}$, $\langle P_5' \rangle_{[4,6]}$

Enhanced charm-loop effect



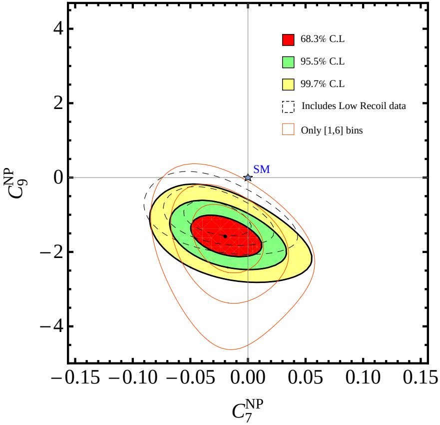


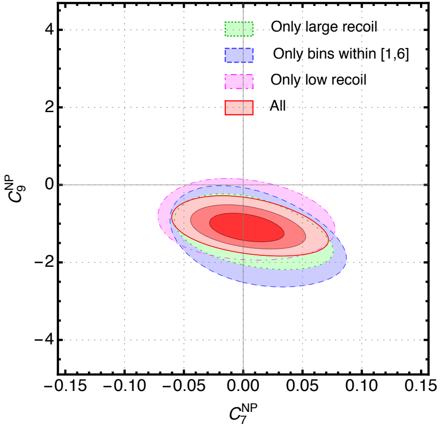
Predictions for Flavour Non-Universality

Assume there is no NP coupling to electrons.

	$R_K[1,6]$	$R_{K^*}[1.1,6]$	$R_\phi[1.1,6]$
SM	1.00 ± 0.01	0.99 ± 0.01 $[1.00 \pm 0.01]$	1.00 ± 0.01
$\mathcal{C}_9^{\rm NP} = -1.13$	0.78 ± 0.01	0.86 ± 0.08 $[0.84 \pm 0.02]$	0.84 ± 0.02
$\mathcal{C}_9^{\rm NP} = -\mathcal{C}_{9'}^{\rm NP} = -1.09$	1.00 ± 0.01	0.78 ± 0.14 $[0.67 \pm 0.03]$	0.74 ± 0.03
$\mathcal{C}_9^{\rm NP} = -\mathcal{C}_{10}^{\rm NP} = -0.70$	0.69 ± 0.01	0.72 ± 0.03 $[0.70 \pm 0.01]$	0.70 ± 0.01
$\mathcal{C}_9^{\rm NP} = -1.17, \mathcal{C}_{9'}^{\rm NP} = 0.70$	0.90 ± 0.01	0.80 ± 0.12 $[0.76 \pm 0.03]$	0.76 ± 0.03
$\mathcal{C}_9^{\rm NP} = -1.15, \mathcal{C}_{10}^{\rm NP} = 0.20$	0.73 ± 0.01	0.80 ± 0.08 $[0.78 \pm 0.02]$	0.78 ± 0.02
$\mathcal{C}_9^{\rm NP} = -1.21, \mathcal{C}_{10'}^{\rm NP} = -0.35$	0.86 ± 0.01	0.78 ± 0.11 $[0.76 \pm 0.02]$	0.76 ± 0.02
$\left.\begin{array}{l}\mathcal{C}_9^{\rm NP} = -\mathcal{C}_{9'}^{\rm NP} = -1.09 \\ \mathcal{C}_{10}^{\rm NP} = -\mathcal{C}_{10'}^{\rm NP} = -0.03\end{array}\right\}$	1.00 ± 0.01	0.79 ± 0.14 $[0.75 \pm 0.03]$	0.75 ± 0.03
$\left.\begin{array}{l}\mathcal{C}_9^{\rm NP} = -\mathcal{C}_{9'}^{\rm NP} = -1.16 \\ \mathcal{C}_{10}^{\rm NP} = \mathcal{C}_{10'}^{\rm NP} = -0.21\end{array}\right\}$	0.90 ± 0.01	0.75 ± 0.13 $[0.72 \pm 0.04]$	0.72 ± 0.03

Comparison w.r.t 2013





Conclusions

- Fits to $b \to s\gamma,\ s\ell\ell$ were a curiosity in 2012
  By 2015 they are a serious industry.
- Around 100 observables, many $\sim 1\sigma$, several $> 2\sigma$ w.r.t SM.
- Global fits point to a $\gtrsim 4\sigma$ tension w.r.t the SM.
- Best-fit scenarios provide good fits to data, with
  - compatibility between BRs and AOs
  - compatibility between different modes
  - compatibility between different q^2 regions
  - agreement between different form-factor approaches
- Fit results seem robust under
  - power corrections
  - charm-loop effects

  correlations must play an important role (not absolute freedom after all!).
- Important to establish to what extent these best fits scenarios can be realised in renormalizable models (many extremely interesting papers already).