Constraints on $|\Delta B| = |\Delta S| = 1$ Wilson Coefficients

Danny van Dyk
in collaboration with
Christoph Bobeth and Frederik Beaujean

2013 EPS Conference on High Energy Physics
July 19th 2013

Theor. Physik 1

UNIVERSITÄT SIEGEN

DFG FOR 1873

Effective Field Theory for $b \to s\ell^+\ell^-$ FCNCs

Flavor Changing Neutral Current (FCNC)

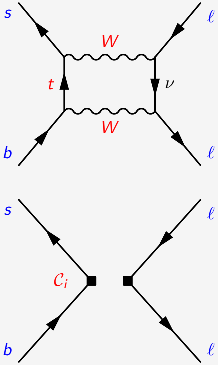
- expand amplitudes in $G_\mathrm{F} \sim 1/M_W^2$ (OPE)
- operators (matrix elem. below $\mu_b \simeq m_b$)

$$\mathcal{O}_i \equiv \left[\bar{s}\Gamma_i b\right] \left[\bar{\ell}\Gamma'_i \ell\right]$$

- Wilson coefficients (above $\mu_b \simeq m_b$)

$$\mathcal{C}_i \equiv \mathcal{C}_i(M_W, M_Z, m_t, \ldots)$$

- use $\mathcal{C}_i = \mathcal{C}_i(\mu_b = 4.2\mathrm{GeV})$



Effective Hamiltonian

$$\mathcal{H} = -\frac{4G_\mathrm{F}}{\sqrt{2}} \frac{\alpha_e}{4\pi} \left[V_{tb}V_{ts}^* \sum_i \mathcal{C}_i \mathcal{O}_i + O\left(V_{ub}V_{us}^*\right)\right] + \mathrm{h.c.}$$

Effective Field Theory for $b \to s\ell^+\ell^-$ FCNCs

Flavor Changing Neutral Current (FCNC)

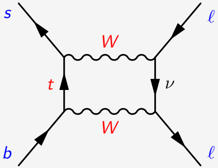
- expand amplitudes in $G_{\mathrm{F}} \sim 1/M_W^2$ (OPE)
- operators (matrix elem. below $\mu_b \simeq m_b$)

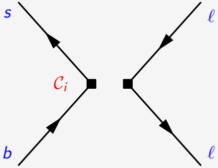
$$\mathcal{O}_i \equiv \left[\bar{s}\Gamma_i b\right] \left[\bar{\ell}\Gamma'_i \ell\right]$$

- Wilson coefficients (above $\mu_b \simeq m_b$)

$$\mathcal{C}_i \equiv \mathcal{C}_i(M_W, M_Z, m_t, \dots)$$

- use $\mathcal{C}_i = \mathcal{C}_i(\mu_b = 4.2\text{GeV})$





Decay Modes

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

Model Independent Framework

Basis of Operators $\mathcal{O}_i$

- include as many $\mathcal{O}_i$ beyond SM as needed/as few as possible
- balancing act, test statistically if choice of basis describes data well!

Wilson Coefficients $\mathcal{C}_i$

- treat $\mathcal{C}_i$ as uncorrelated, generalized couplings
- constrain their values from data
- confront new physics models with constraints

Model Independent Framework

Operators/Wilson Coefficients

SM:

$$\mathcal{O}_7 = \frac{m_b}{e}[\bar{s}\sigma_{\mu\nu}P_R b]F^{\mu\nu} \qquad \mathcal{O}_{9(10)} = [\bar{s}\gamma_\mu P_L b]\,[\bar{\ell}\gamma^\mu(\gamma_5)\ell]$$

chirality flipped (beyond SM)

$$\mathcal{O}_{7'} = \frac{m_b}{e}[\bar{s}\sigma_{\mu\nu}P_L b]F^{\mu\nu} \qquad \mathcal{O}_{9'(10')} = [\bar{s}\gamma_\mu P_R b]\,[\bar{\ell}\gamma^\mu(\gamma_5)\ell]$$

Model Independent Framework

Operators/Wilson Coefficients

SM:

$$\mathcal{O}_7 = \frac{m_b}{e}[\bar{s}\sigma_{\mu\nu}P_R b]F^{\mu\nu} \qquad \mathcal{O}_{9(10)} = [\bar{s}\gamma_\mu P_L b]\,[\bar{\ell}\gamma^\mu(\gamma_5)\ell]$$

chirality flipped (beyond SM)

$$\mathcal{O}_{7'} = \frac{m_b}{e}[\bar{s}\sigma_{\mu\nu}P_L b]F^{\mu\nu} \qquad \mathcal{O}_{9'(10')} = [\bar{s}\gamma_\mu P_R b]\,[\bar{\ell}\gamma^\mu(\gamma_5)\ell]$$

Scenario — only real-valued $\mathcal{C}_i \Rightarrow$ no BSM CPV

vary **SM** $\mathcal{C}_7$, $\mathcal{C}_9$, $\mathcal{C}_{10}$ and

- hadronic parameters
- CKM Wolfenstein parameters
- quark masses

$\mathcal{C}_1, \ldots \mathcal{C}_6, \mathcal{C}_8$ as in the SM

Sensitivity to Parameters

	$\mathcal{C}_7$	$\mathcal{C}_9$	$\mathcal{C}_{10}$
$B_s \to \mu^+\mu^-$	–	–	✓
$B \to X_s\gamma$	✓	–	–
$B \to X_s\ell^+\ell^-$	✓	✓	✓
$B \to K^*\gamma$	✓	–	–
$B \to K^*\ell^+\ell^-$	✓	✓	✓
$B \to K\ell^+\ell^-$	✓	✓	✓

Measurements Entering Analysis: 81

$B \to K^* \ell^+ \ell^-$ $q^2 \in [1, 6]\,\mathbf{GeV}^2$, $q^2 \geq M_{\psi'}^2$

- $\mathcal{B}$, A_{FB} ($A_{\mathrm{T}}^{\mathrm{re}}$), F_{L}, A_{T}^{2} (S_3)
- ATLAS, BaBar, Belle, CDF, CMS, LHCb

$B \to K^* \gamma$

- $\mathcal{B}$, $S_{K^*\gamma}$, $C_{K^*\gamma}$
- BaBar, Belle, CLEO

$B \to K \ell^+ \ell^-$ $q^2 \in [1, 6]\,\mathbf{GeV}^2$, $q^2 \geq M_{\psi'}^2$

- $\mathcal{B}$
- BaBar, Belle, CDF, LHCb

$B \to X_s \gamma$ $E_{\mathbf{min}}^{\gamma} = 1.8\,\mathbf{GeV}$

- $\mathcal{B}$
- BaBar, Belle, CLEO

$B_s \to \mu^+ \mu^-$

- time-int. $\mathcal{B}$
- LHCb

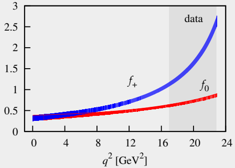
$B \to X_s \ell^+ \ell^-$ $q^2 \in [1, 6]\,\mathbf{GeV}^2$

- $\mathcal{B}$
- BaBar, Belle

Further Theory Constraints

Form Factors from Lattice QCD (LQCD) [HPQCD arxiv:1306.2384]

- $B \to K$ form factors available from LQCD
  - data only at high q^2: $17 - 23\,\text{GeV}^2$
  - no data points given
- reproduce 3 data points from z-parametrization
  - $q^2 = 17\,\text{GeV}^2$, $20\,\text{GeV}^2$, $23\,\text{GeV}^2$
  - use as constraint, incl. covariance matrix



$B \to K^*$ Form Factor (FF) Relation at $q^2 = 0$

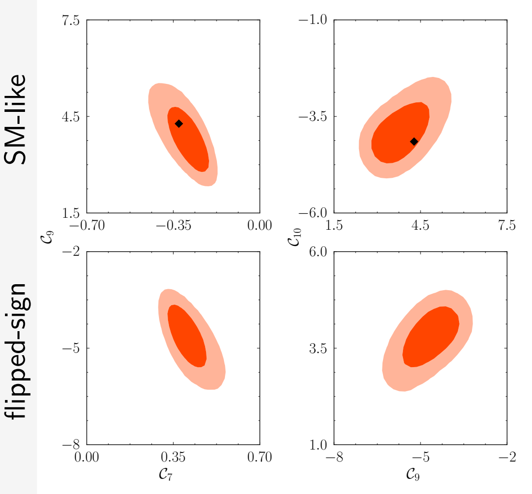
- FF $V, A_1 \propto \xi_\perp + \dots$ [Charles et al. hep-ph/9901378]
  - no α_s corrections [Burdmann/Hiller hep-ph/0011266, Beneke/Feldmann hep-ph/0008255]
  - Large Energy Limit:

$$\frac{V(0)}{A_1(0)} \simeq 1.33 \pm 0.4$$

- see also FF fits by [Hambrock/Hiller/Schacht/Zwicky DO-TH 13/13 in preparation]

Preliminary Results (SM Basis)

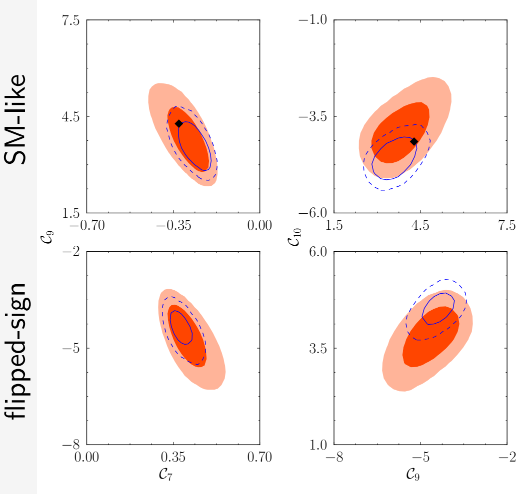
$\mathcal{C}_7, \mathcal{C}_9, \mathcal{C}_{10}$ vs. exclusive decay data up to 2012 [Beaujean et al. 1205.1838]



♦: Standard Model

Preliminary Results (SM Basis)

$\mathcal{C}_7, \mathcal{C}_9, \mathcal{C}_{10}$ vs. exclusive decay data up to 2013



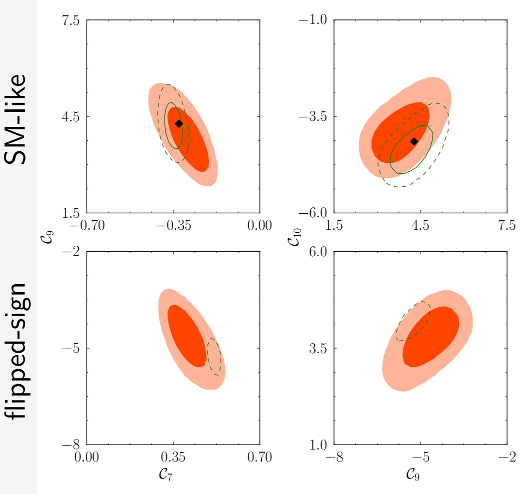
Summary 2013(excl)

- uncertainty reduced by ~ 2
- SM at the border of 1σ

♦: Standard Model

Preliminary Results (SM Basis)

$\mathcal{C}_7, \mathcal{C}_9, \mathcal{C}_{10}$ vs. all data up to 2013



Summary 2013(excl)

- uncertainty reduced by ~ 2
- SM at the border of 1σ

Summary 2013(all)

- $\mathcal{C}_7$ much more precise
- flipped-sign excluded at 1σ
- good agreement with SM

◆: Standard Model

Preliminary Numeric Results

		$\mathcal{C}_7$	$\mathcal{C}_9$	$\mathcal{C}_{10}$
2012	68 %	$[-0.34, -0.23] \cup [0.35, 0.45]$	$[-5.2, -4.0] \cup [3.1, 4.4]$	$[-4.4, -3.4] \cup [3.3, 4.3]$
	95 %	$[-0.41, -0.19] \cup [0.31, 0.52]$	$[-5.9, -3.5] \cup [2.6, 5.2]$	$[-4.8, -2.8] \cup [2.7, 4.7]$
	modes	$\{-0.28\} \cup \{0.40\}$	$\{-4.56\} \cup \{3.64\}$	$\{-3.92\} \cup \{3.86\}$
2013 (all)	68 %	$[-0.37, -0.32] \cup \emptyset$	$\emptyset \cup [3.7, 4.6]$	$[-4.7, -4.0] \cup \emptyset$
	95 %	$[-0.40, -0.30] \cup [0.50, 0.53]$	$[-5.5, -4.9] \cup [3.2, 5.3]$	$[-5.1, -3.4] \cup [4.0, 4.5]$
	modes	$\{-0.347\} \cup \{0.513\}$	$\{-5.21\} \cup \{4.11\}$	$\{-4.40\} \cup \{4.31\}$
SM	central	$\{-0.327\} \cup \emptyset$	$\emptyset \cup \{4.28\}$	$\{-4.15\} \cup \emptyset$

Goodness of Fit

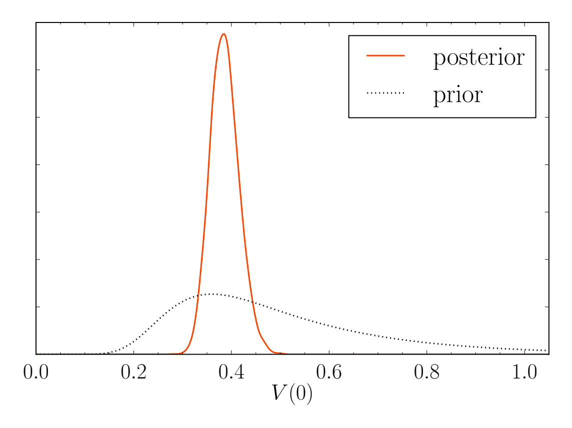
- pull-based p-value at SM mode decreased
  - p-value 2012: 0.75
  - p-value 2013(all): 0.16
- still a good fit
- SM(all) p-value: 0.16

- largest pulls

-3.5σ F_L, [1, 6], BaBar 2012
-2.6σ F_L, [1, 6], ATLAS 2013
$+2.5\sigma$ $\mathcal{B}$, [16,19.21], Belle 2009
$+2.2\sigma$ A_{FB}, [16,19], ATLAS 2013

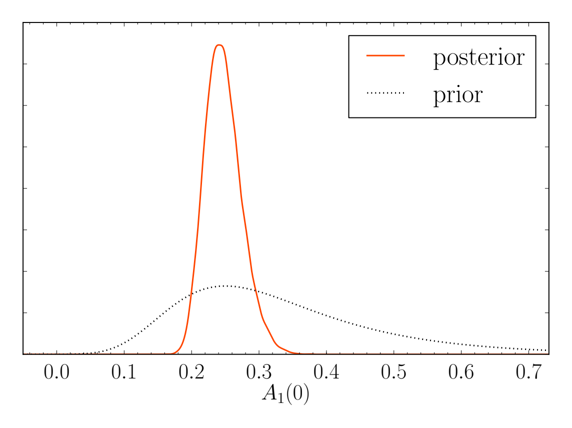
- rest below 2σ

Results for $B \to K^{(*)}$ Form Factors



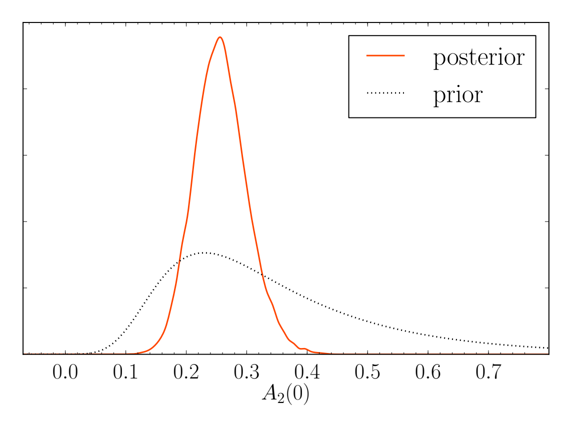
- more precise than prior
- $B \to K^*$: $\xi_\perp$ from
  - $B \to X_s\gamma$
  - $B \to K^*\gamma$
  - $B \to K^*\ell^+\ell^-$
  - theory input
- results @ 68% CL
  - $V(0) = 0.37 \pm 0.03$

Results for $B \to K^{(*)}$ Form Factors



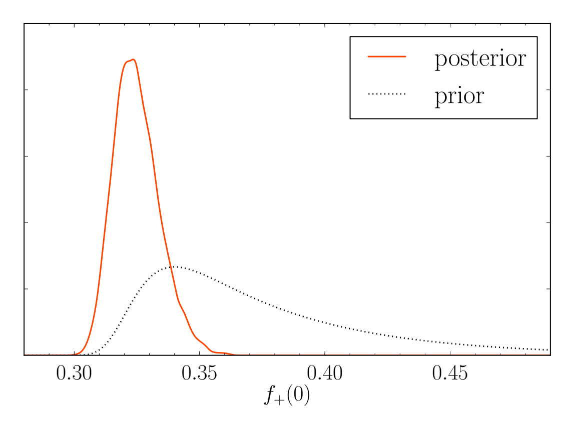
- more precise than prior
- $B \to K^*$: $\xi_\perp$ from
  - $B \to X_s \gamma$
  - $B \to K^* \gamma$
  - $B \to K^* \ell^+ \ell^-$
  - theory input
- results @ 68% CL
  - $V(0) = 0.37 \pm 0.03$
  - $A_1(0) = 0.24 \pm 0.03$

Results for $B \to K^{(*)}$ Form Factors



- more precise than prior
- $B \to K^*$: $\xi_\perp$ from
  - $B \to X_s\gamma$
  - $B \to K^*\gamma$
  - $B \to K^*\ell^+\ell^-$
  - theory input
- results @ 68% CL
  - $V(0) = 0.37 \pm 0.03$
  - $A_1(0) = 0.24 \pm 0.03$
  - $A_2(0) = 0.24 \pm 0.04$

Results for $B \to K^{(*)}$ Form Factors



- more precise than prior
- $B \to K$:
  - $B \to K\ell^+\ell^-$
  - Lattice
- results @ 68% CL
  - $f_+(0) = 0.32 \pm 0.01$
  - $b_1^+(0) = -2.1 \pm 0.2$
- tension (excl only)
  - LHCb lo q^2: -1.4σ
  - LHCb hi q^2: $+1.4\sigma$
  - Lattice: $+1.4\sigma$

Conclusion

Summary

- global analyses of available $b \to s\{\gamma, \ell^+\ell^-\}$ data
- preliminary SM basis with all data
  - SM-like solution preferred over flipped signs with 9 to 1
  - p-value 0.16
- data also allows inference of hadronic quantities

Outlook

- SM' basis work in progress
- looking forward to further LHC analyses and the prospects of Belle-II

Backup Slides

Priors and Parametrizations (I)

Form Factors [Khodjamirian et al. 1006.4945]

- values @ $q^2 = 0$ and slope
- z-parametrization
- asymmetric priors, use LogGamma function

CKM [update of hep-ph/0012308]

- Wolfenstein parametrization
- UTfit pre-Moriond2013, tree-level data only

Quark Masses [PDG]

Priors and Parametrizations (I) - Subleading

parametrize unknown subleading contributions

$B \to K^* \ell^+ \ell^-$

- lo q^2: 6 parameters, one per amplitude
- hi q^2: 3 parameters

$B \to K \ell^+ \ell^-$

- lo q^2: 1 parameter
- hi q^2: 1 parameter

for all: Gaussian with mode at $\Lambda_{\text{QCD}}/m_b \simeq 0.1$