More Opportunities to Probe New Physics in $b \rightarrow s \ell^+ \ell^-$

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based on work with
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$d\mathcal{B}/dq^2(\bar{B} \rightarrow \bar{K}^{(*)}\ell^+\ell^-)$

SM predictions for $\bar{B} \rightarrow \bar{K}^*\ell^+\ell^-$, $B^+ \rightarrow K^+\ell^+\ell^-$

C. Bobeth, G. Hiller, DvD '10; C. Bobeth, G. Hiller, DvD, C. Wacker (in prep.)

Belle + CDF: $\sim 420 \ B \rightarrow K^*\ell^+\ell^-$ events, $\sim 440 \ B^+ \rightarrow K^+\ell^+\ell^-$ events

LHCb: $\sim 300 \ B \rightarrow K^*\ell^+\ell^-$ events in 309 pb$^{-1}$ M. Patel '11
\( |\Delta B| = 1 \) Effective Field Theory

- low energy effective theory below \( \sim M_W \)
- separates high-energy (\( \equiv \) short-distance) from low-energy (\( \equiv \) long-distance) physics
- \( |\Delta B| = 1 \) effective Hamiltonian:

\[
\mathcal{H}^{\text{eff}} = \mathcal{H}_{e,\mu,\tau}^{u,d,s,c,b} + \sum_i C_i(\mu) \mathcal{O}_i(\mu)
\]

- most important operators in SM basis

\[
\mathcal{O}_{9(10)} = [\bar{s}\gamma_\mu P_L b][\bar{\ell}\gamma^\mu (\gamma_5)\ell]
\]

\[
\mathcal{O}_7 = \bar{m}_b(\mu)[\bar{s}\sigma^{\mu\nu} P_R b] F_{\mu\nu}
\]
Low Recoil Framework for $\bar{B} \to \bar{K}(*)\ell^+\ell^-$ (new, 2010+)

- hadronic matrix elements $\langle K(*)\ell^+\ell^-|O_i(\mu_b)|B\rangle$ receive contributions from $b \to sq\bar{q}$ operators

- hard momentum transfer $q^2 \sim m_B^2$ allows local OPE
  
  B. Grinstein, D. Pirjol '04

- improved Isgur-Wise relations B. Grinstein, D. Pirjol '02

\[ \mathcal{A} \propto \langle K(*)|\mathcal{H}^{\text{eff}}|B\rangle \]

$\Rightarrow$ fewer independent hadronic matrix elements:

- $B \to K^*\ell^+\ell^-$: 7 $\to$ 4,
- $B \to K\ell^+\ell^-$: 3 $\to$ 2

- recent OPE study M. Beylich, G. Buchalla, Th. Feldmann '11

- use observables to check performance of OPE (cf. $H_T^{(1)}$ later on)
Benefits of Low Recoil for $\bar{B} \rightarrow \bar{K}^* \ell^+ \ell^-$

- all 6 transversity amplitudes $A_{i}^{L,R}$ factorize in the SM basis of operators

$$A_{i}^{L,R}(q^2) = c_{i}^{L,R} \times f_i, \quad i = \perp, \parallel, 0$$

- corrections to factorization suppressed, start only at $\mathcal{O}(C_7 \Lambda / M_B)$ and $\mathcal{O}(\alpha_s \Lambda / M_B)$.

- $c_{i}^{L,R}$ depend only on short-distance physics

- $f_i$ depend only on long-distance physics

- only 2 short-distance couplings in observable at low recoil

$$\rho_1 = \left| C_{9}^{\text{eff}} + \kappa(\mu) \frac{2 m_b(\mu) m_B}{q^2} C_{7}^{\text{eff}} \right|^2 + \left| C_{10} \right|^2 \propto |c_L|^2 + |c_R|^2$$

$$\rho_2 = \Re \left\{ (C_{9}^{\text{eff}} + \kappa(\mu) \frac{2 m_b(\mu) m_B}{q^2} C_{7}^{\text{eff}}) C_{10}^* \right\} \propto |c_L|^2 - |c_R|^2$$
Low Recoil Observables - CP symmetric

- observables either depend on $\rho_1 (B, \ldots)$, $\rho_2/\rho_1 (A_{FB}, \ldots)$ or don’t depend on short-distance physics ($F_L, \ldots$)
- find observables of angular distribution in which hadronic uncertainties cancel

$$
H_T^{(1)} = \frac{\sqrt{2}J_4}{\sqrt{-J_2^c(2J_2^s - J_3)}} \quad H_T^{(2)} = \beta_\ell \frac{J_5}{\sqrt{-2J_2^c(2J_2^s + J_3)}} \quad H_T^{(3)} = \beta_\ell \frac{J_6}{2\sqrt{(2J_2^s)^2 - J_3^2}}
$$

- $H_T^{(2)} = H_T^{(3)} = 2\rho_2/\rho_1$ \text{C.Bobeth,G.Hiller,DvD '10}
  \Rightarrow \text{test of the SM}
- model-independently: $H_T^{(1)} = 1$
  \Rightarrow \text{test of the OPE C.Bobeth,G.Hiller,DvD in prep.}
- form factor relations at low recoil
  \Rightarrow \text{test form factors from the lattice Liu et al. '11}
Low Recoil Observables - CP asymmetric

- with CPV beyond the SM we have 4 short-distance couplings:

\[ \rho_1, \bar{\rho}_1 \equiv \rho_1[\delta W \rightarrow -\delta W], \quad \rho_2, \bar{\rho}_2 \equiv \rho_2[\delta W \rightarrow -\delta W] \]

- introduces two independent CP asymmetries with reduced hadr. uncertainties

\[
\begin{align*}
    a^{(1)}_{\text{CP}} &= \frac{\rho_1 - \bar{\rho}_1}{\rho_1 + \bar{\rho}_1} \\
    a^{(2)}_{\text{CP}} &= \frac{\rho_2}{\rho_1} \frac{\rho_1 - \bar{\rho}_1}{\rho_1 + \bar{\rho}_1} \\
    a^{(3)}_{\text{CP}} &= 2 \frac{\rho_2 - \bar{\rho}_2}{\rho_1 + \bar{\rho}_1}
\end{align*}
\]

- \( a^{(3)}_{\text{CP}} \) amounts to extracting \( H_T^{(2,3)} \) from untagged samples with equal numbers of \( B, \bar{B} \).

- \( (B_s, \bar{B}_s) \rightarrow \phi \ell^+ \ell^- \): mixing induces \( a_{\text{mix}}^{(3)} \rightarrow a_{\text{CP}}^{(3)} \) for \( \Delta \Gamma / \Gamma \rightarrow 0 \)

C.Bobeth, G.Hiller, DvD '11
Low Recoil Observables - $B \to K \ell^+ \ell^-$

- in $\bar{B} \to \bar{K} \ell^+ \ell^-$, $\ell = e, \mu$: only one short-distance coupling!
  identical coupling as in $\bar{B} \to \bar{K}^* \ell^+ \ell^-$:

  $$\rho_1[\bar{B} \to \bar{K} \ell^+ \ell^-] = \rho_1[\bar{B} \to \bar{K}^* \ell^+ \ell^-]$$

- as a consequence

  $$A_{CP}[\bar{B} \to \bar{K} \ell^+ \ell^-] = a^{(1)}_{CP}[\bar{B} \to \bar{K}^* \ell^+ \ell^-]$$

- improve significance by combining $B \to K^* \ell^+ \ell^-$ with $B \to K \ell^+ \ell^-$ data

C.Bobeth, G.Hiller, DvD, C.Wacker (in prep.)
Why $H_T^{(i)}$ and $a_{CP}^{(i)}$?

- precision observables at low recoil!
- form factors/hadronic uncert. are biggest source of theoretical uncert.
- $H_T^{(2,3)}$ provide identical information as $A_{FB} \propto \rho_2/\rho_1$ but theoretical uncert. much smaller!

SM prediction at Low Recoil:

\[ \langle A_{FB} \rangle = -0.41 \pm 0.07 \ (17\%) \quad \langle H_T^{(3)} \rangle = -0.96 \pm 0.01 \ (1\%) \]

- $H_T^{(3)}$ can be measured at LHCb U.Egede '11
  extraction from simultaneous fits of $\theta_\ell$ and $\phi$ projections
Model Independent Analysis

- treat short-distance couplings $C_{7,9,10}$ as free parameters
- allow for CPV beyond the SM through complex values
  $\Rightarrow |C_{7,9,10}|$ and $\phi_{7,9,10}$
- perform parameter scan and calculate $\chi^2$
- modify $\chi^2$: within theory uncertainty set $\chi^2 = 0$

Calculation of observables and parameter scan performed using EOS:

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

DvD, C. Bobeth, F. Beaujean, C. Wacker
Results for complex-valued $C_{9,10} - B \rightarrow K^* \ell^+ \ell^-$ only

green square marks the SM

C. Bobeth, G. Hiller, DvD '11
Results for complex-valued $C_{9,10}$ - Incl. $B \to K\ell^+\ell^-$

Preliminary

from combined analyses we find @ 95% CL

$0.0 \leq |C_9| \leq 7$

$0.8 \leq |C_{10}| \leq 5.8$

$B(\bar{B}_s \to \mu^+\mu^-) < 8.5 \cdot 10^{-9}$

$q_{0,FB}^2(\bar{B}^0 \to \bar{K}^* \mu^+\mu^-) > 2.3 \text{ GeV}^2$

black solid (dotted) contour: 95% CL (68% CL)

constraints from $\bar{B} \to \bar{K}^* \ell^+\ell^-$ data only
Conclusions

- ...more opportunities to probe New Physics in $b \to s \ell^+ \ell^-$

- ...factorization of transversity amplitudes
  $\Rightarrow$ observables overconstrain short-distance couplings

- ...identical short-distance coupling in $B \to K^* \ell^+ \ell^-$ and $B \to K \ell^+ \ell^-$
  $\Rightarrow$ increase statistics by combining both decay modes

for current works, see also slides from recent workshop:

“Rare B Decays @ Low Recoil (bsll2011)”, DESY
http://indico.desy.de/events/bsll2011
References


M.Patel '11: Talk given at EPS-HEP 2011


U.Egede '11: Talk at bssl2011, DESY, Hamburg
Outline

Backup Slides
Results for complex-valued $C_{9,10} - B \rightarrow K^*\ell^+\ell^-$ only

green square marks the SM, black point marks a benchmark point
black contour: 68% CL constraints from hypothetical $a_{CP}^{(1)}$ of ±0.01 precision at benchmark point C.Bobeth,G.Hiller,DvD '11