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

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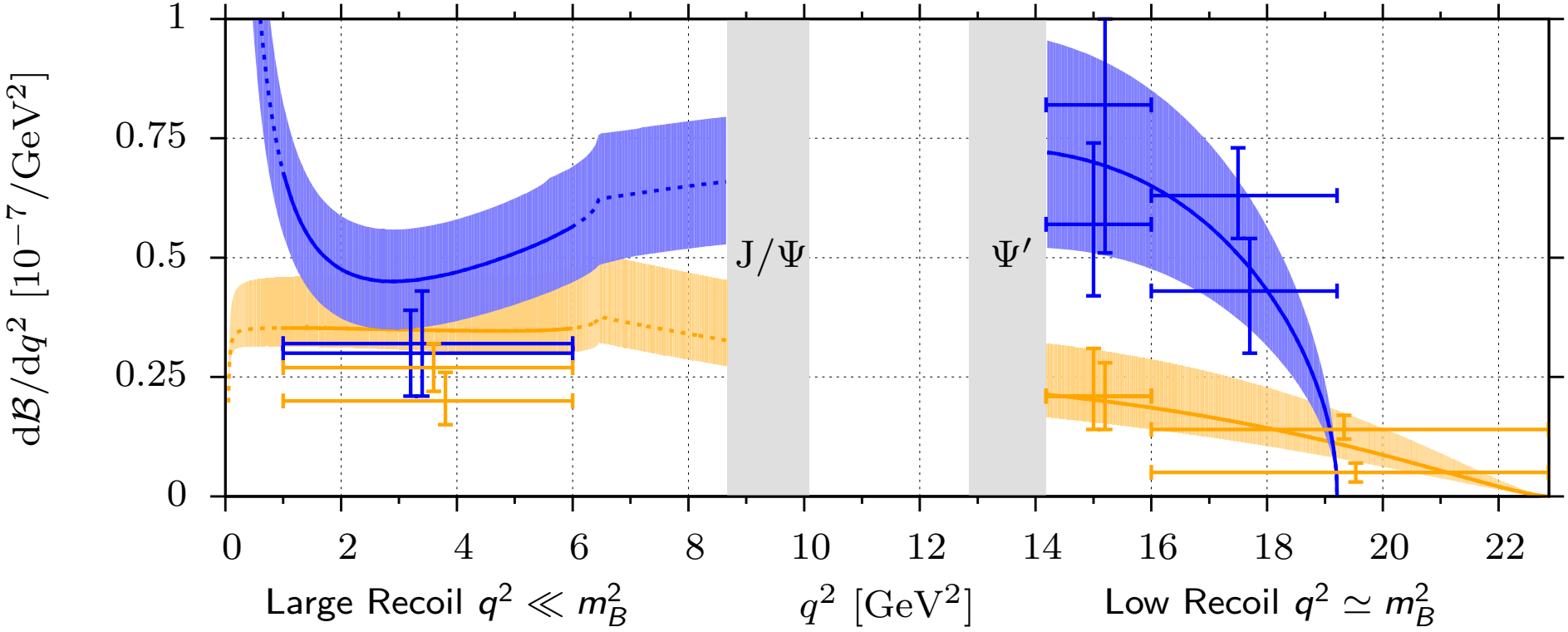
$\mathrm{d}\mathcal{B}/\mathrm{d}q^2(\bar{B} \to \bar{K}^{(*)}\ell^+\ell^-)$

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



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

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

LHCb: ~ 300 $B \to K^*\ell^+\ell^-$ events in 309 pb^{-1} M.Patel '11

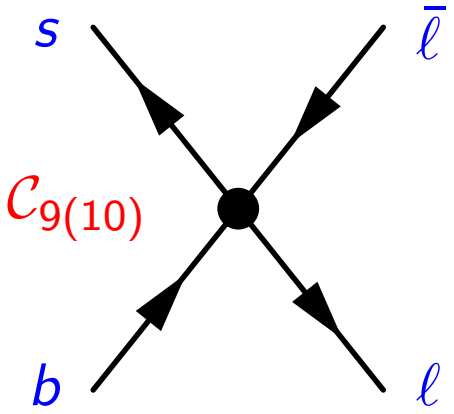
$|\Delta B| = 1$ Effective Field Theory

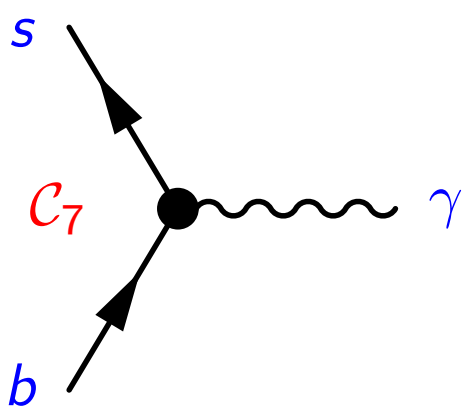
- low energy effective theory below $\sim M_W$
- separates high-energy ($\equiv$ short-distance) from low-energy ($\equiv$ long-distance) physics
- $|\Delta B| = 1$ effective Hamiltonian:

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

- most important operators in SM basis

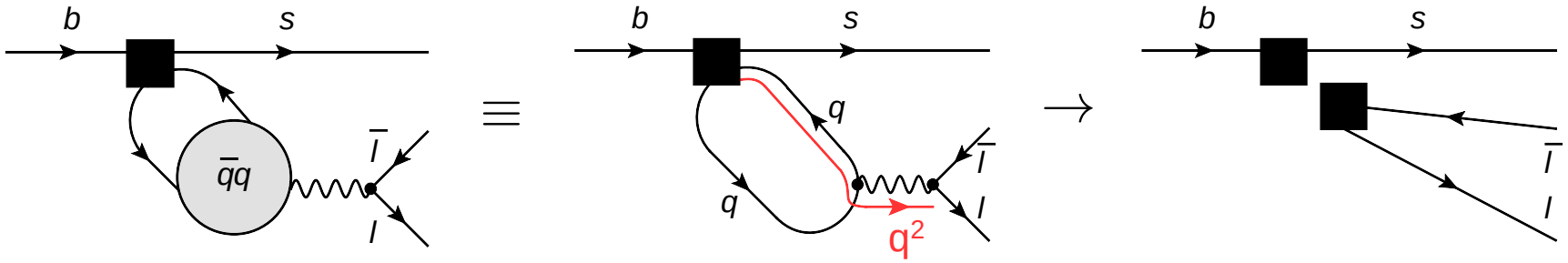
$$\mathcal{O}_{9(10)} = [\bar{s}\gamma_\mu P_L b][\bar{\ell}\gamma^\mu(\gamma_5)\ell] \qquad \mathcal{O}_7 = \overline{m}_b(\mu)[\bar{s}\sigma^{\mu\nu}P_R\, b]F_{\mu\nu}$$





Low Recoil Framework for $\bar{B} \to \bar{K}^{(*)}\ell^+\ell^-$ (new, 2010+)

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



- hard momentum transfer $q^2 \simeq m_B^2$ 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:
  $B \to K^*\ell^+\ell^-$: $7 \to 4$, $\quad B \to K\ell^+\ell^-$: $3 \to 2$
- 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 $\bar{B} \to \bar{K}^* \ell^+ \ell^-$

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

$$A_i^{L,R}(q^2) = c^{L,R} \times f_i, \quad i = \perp, \|, 0$$

- corrections to factorization suppressed, start only at $\mathcal{O}(\mathcal{C}_7 \Lambda / M_B)$ and $\mathcal{O}(\alpha_s \Lambda / M_B)$.
- $c^{L,R}$ depend only on short-distance physics
- f_i depend only on long-distance physics
- only **2** short-distance couplings in observable at low recoil

$$\rho_1 = \left| \mathcal{C}_9^{\text{eff}} + \kappa(\mu) \frac{2 m_b(\mu) m_B}{q^2} \mathcal{C}_7^{\text{eff}} \right|^2 + \left| \mathcal{C}_{10} \right|^2 \propto |c^L|^2 + |c^R|^2$$

$$\rho_2 = \text{Re}\left\{ \left(\mathcal{C}_9^{\text{eff}} + \kappa(\mu) \frac{2 m_b(\mu) m_B}{q^2} \mathcal{C}_7^{\text{eff}} \right) \mathcal{C}_{10}^* \right\} \propto |c^L|^2 - |c^R|^2$$

Low Recoil Observables - CP symmetric

- observables either depend on ρ_1 ($\mathcal{B}$, ...), ρ_2/ρ_1 ($A_{\rm FB}$, ...) or don't depend on short-distance physics ($F_{\rm L}$, ...)
- find observables of angular distribution in which hadronic uncertainties cancel

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

- $H_T^{(2)} = H_T^{(3)} = 2\rho_2/\rho_1$ C.Bobeth,G.Hiller,DvD '10
  $\Rightarrow$ test of the SM
- model-independently: $H_T^{(1)} = 1$
  $\Rightarrow$ test of the OPE C.Bobeth,G.Hiller,DvD in prep.
- form factor relations at low recoil
  $\Rightarrow$ 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:

$$\rho_1, \bar{\rho}_1 \equiv \rho_1[\delta_W \to -\delta_W], \quad \rho_2, \bar{\rho}_2 \equiv \rho_2[\delta_W \to -\delta_W]$$

- introduces two independent CP asymmetries with reduced hadr. uncertainties

$$a_{\rm CP}^{(1)} = \frac{\rho_1 - \bar{\rho}_1}{\rho_1 + \bar{\rho}_1} \qquad a_{\rm CP}^{(2)} = \frac{\frac{\rho_2}{\rho_1} - \frac{\bar{\rho}_2}{\bar{\rho}_1}}{\frac{\rho_2}{\rho_1} + \frac{\bar{\rho}_2}{\bar{\rho}_1}} \qquad a_{\rm CP}^{(3)} = 2\frac{\rho_2 - \bar{\rho}_2}{\rho_1 + \bar{\rho}_1}$$

- $a_{\rm CP}^{(3)}$ amounts to extracting $H_T^{(2,3)}$ from untagged samples with equal numbers of B,$\bar{B}$.
- $(B_s, \bar{B}_s) \to \phi\ell^+\ell^-$: mixing induces $a_{\rm CP}^{mix} \to a_{\rm CP}^{(3)}$ for $\Delta\Gamma/\Gamma \to 0$

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

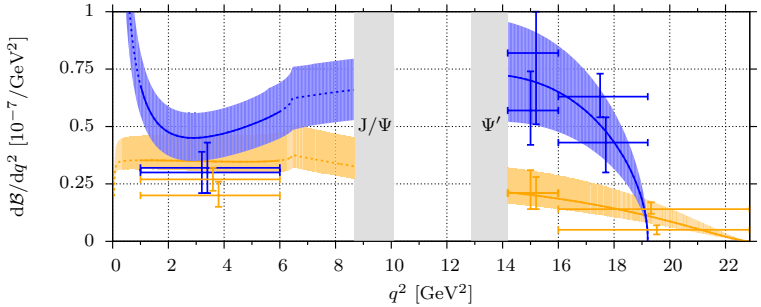
$$A_{\rm CP}[\bar{B} \to \bar{K}\ell^+\ell^-] = a_{\rm CP}^{(1)}[\bar{B} \to \bar{K}^*\ell^+\ell^-]$$

- 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 $a_{\rm CP}^{(i)}$?

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

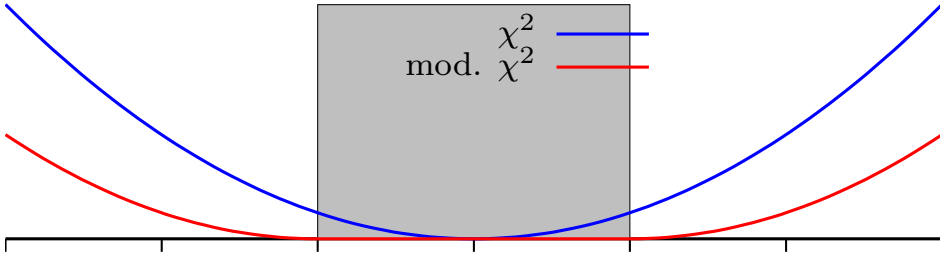


$$\langle A_{\rm FB}\rangle = -0.41 \pm 0.07\ (17\%) \qquad \langle H_T^{(3)}\rangle = -0.96 \pm 0.01\ (1\%)$$

- $H_T^{(3)}$ can be measured at LHCb U.Egede '11
  extraction from simultaneous fits of θ_ℓ and ϕ projections

Model Independent Analysis

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

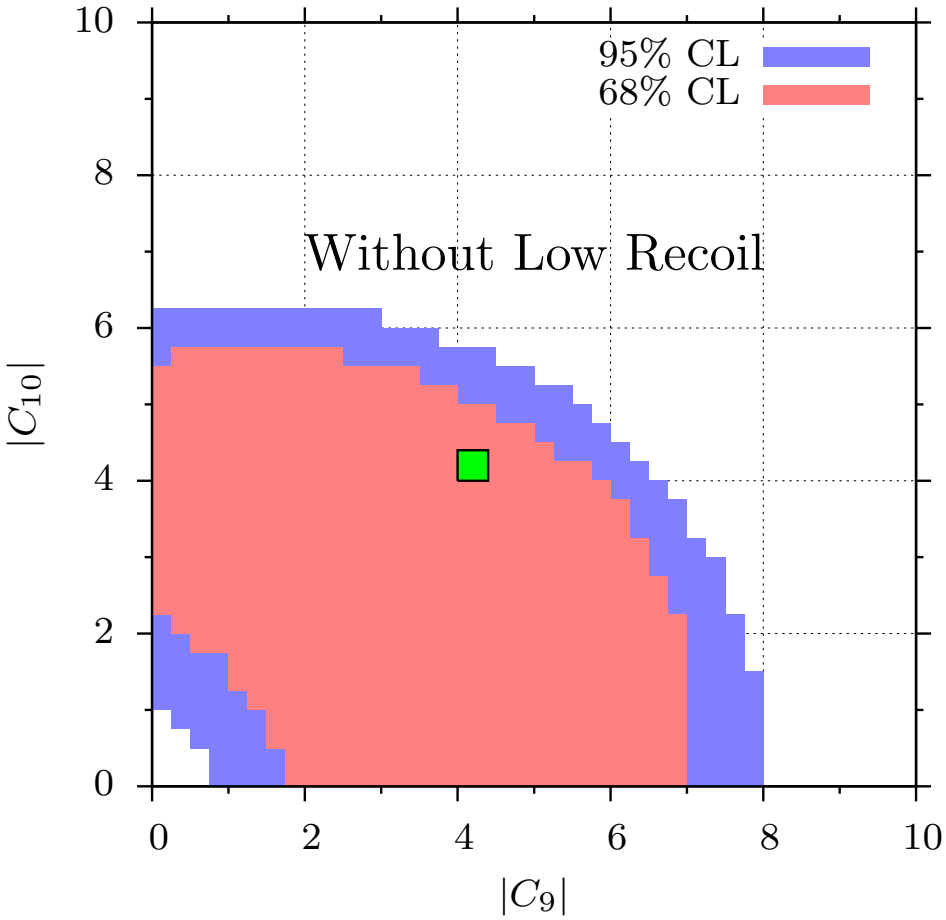


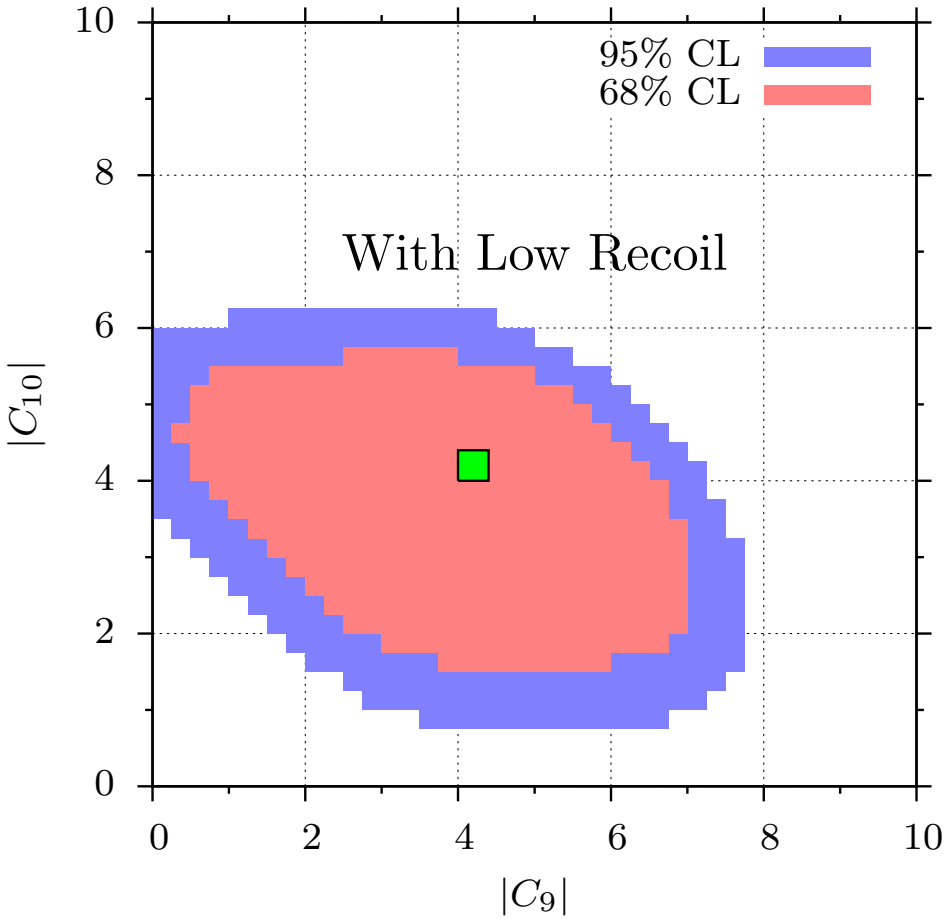
calculation of observables and parameter scan performed using EOS:

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

DvD,C.Bobeth,F.Beaujean,C.Wacker

Results for complex-valued $\mathcal{C}_{9,10}$ - $B \to K^* \ell^+ \ell^-$ only

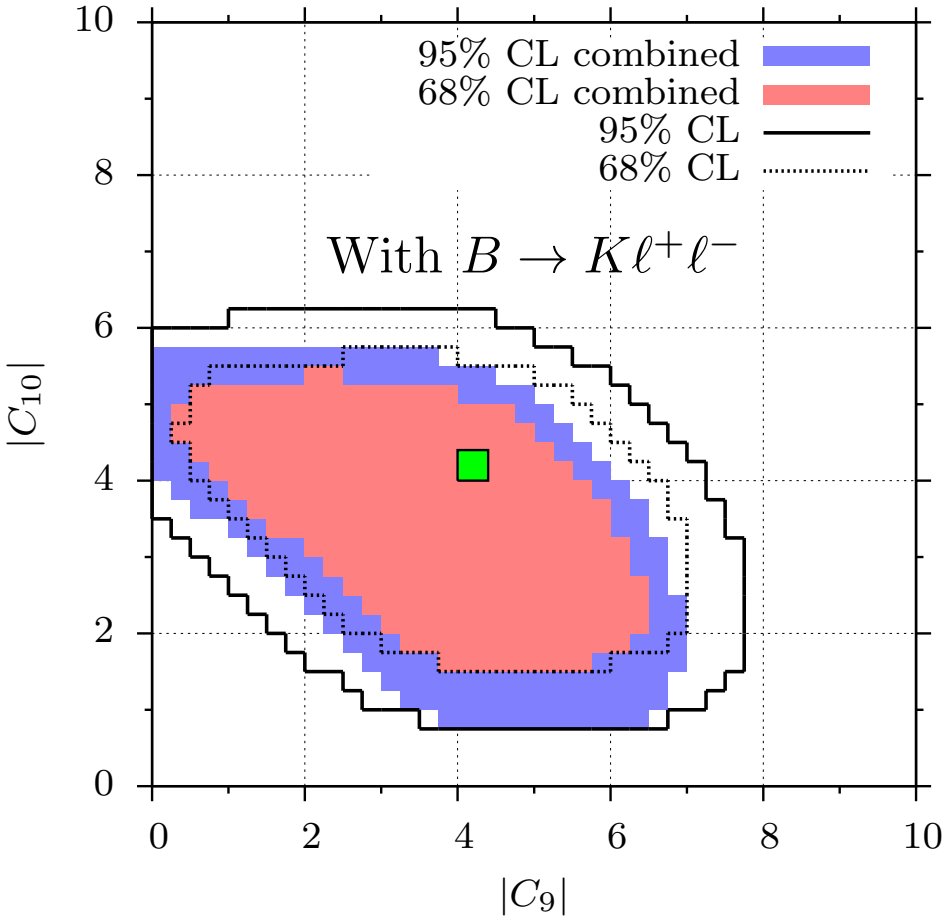




green square marks the SM

C.Bobeth,G.Hiller,DvD '11

Results for complex-valued $\mathcal{C}_{9,10}$ - Incl. $B \to K\ell^+\ell^-$



green square marks the SM

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

Preliminary

from combined analyses we find @95% CL

$0.0 \leq |\mathcal{C}_9| \leq 7$

$0.8 \leq |\mathcal{C}_{10}| \leq 5.8$

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

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

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

C.Bobeth,G.Hiller,DvD '10: JHEP 1007 (2010) 098 [arXiv:1006.5013 [hep-ph]]

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

B.Grinstein,D.Pirjol '04: Phys.Rev. D70 (2004) 114005 [arXiv:hep-ph/0404250]

B.Grinstein,D.Pirjol '02: Phys.Lett. B533 (2002) 8-16 [arXiv:hep-ph/0201298]

M.Beylich,G.Buchalla,Th.Feldmann '11: Eur.Phys.J. C71 (2011) 1635 [arXiv:1101.5118 [hep-ph]]

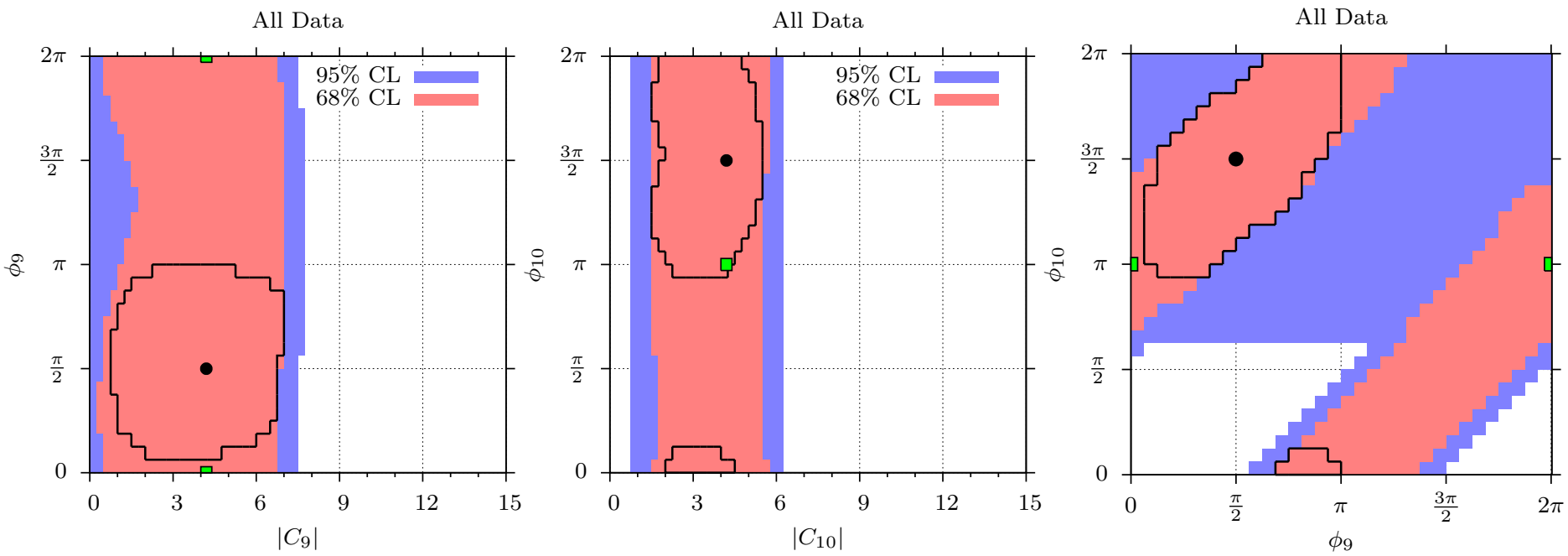
C.Bobeth,G.Hiller,DvD '11: accepted by JHEP [arXiv:1105.0376 [hep-ph]]

U.Egede '11: Talk at bsll2011, DESY, Hamburg

Outline

Backup Slides

Results for complex-valued $\mathcal{C}_{9,10}$ - $B \to K^* \ell^+ \ell^-$ only



green square marks the SM, black point marks a benchmark point

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