The Benefits of $\bar{B} \to \bar{K}^* \ell^+ \ell^-$ at Low Recoil

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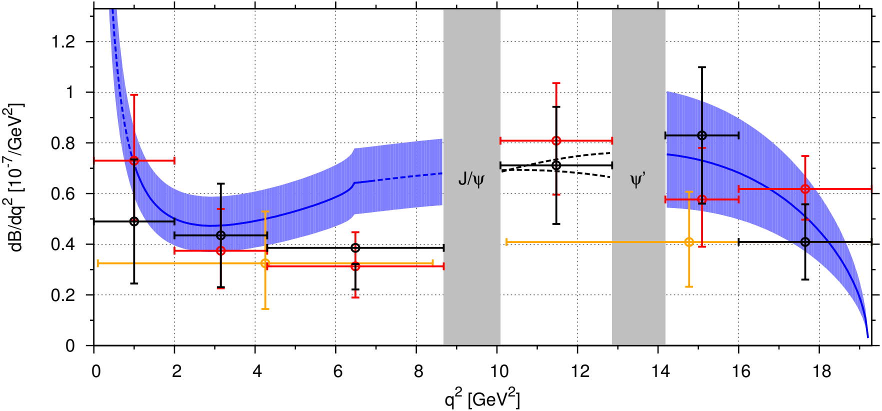
$\rightarrow$ JHEP07(2010)098

$\mathrm{d}\mathcal{B}/\mathrm{d}q^2(B \to K^*\ell^+\ell^-), \ell = e, \mu$ in the SM

SM Result for $\mathrm{d}\mathcal{B}/\mathrm{d}q^2$

Exp. Data: BaBar'06, Belle'09, CDF'09



Large Recoil $q^2 \ll m_b^2$

$q^2 \simeq m_b^2$ Low Recoil

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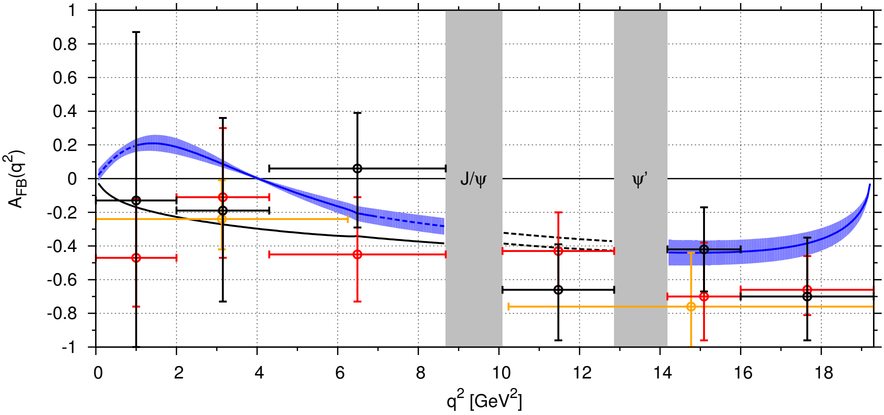
$A_{\mathrm{FB}}(B \to K^* \ell^+ \ell^-), \ell = e, \mu$ in the SM

SM Result for A_{FB}

Exp. Data: BaBar'08, Belle'09, CDF'09



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Low Recoil Framework for $\bar{B} \to \bar{K}^* \ell^+ \ell^-$

developed by B.Grinstein, D.Pirjol '04

Improved Isgur-Wise Form Factor Relations

- relate dipole form factors T_i, $i = 1, 2, 3$ to vector/axial vector form factors V, A_1, A_2
- reduce number of QCD form factors: $7 \to 4$

$$T_i \sim \langle K^* | \sigma_{\mu\nu} | B \rangle$$
$$V, A_i \sim \langle K^* | \gamma_\mu | B \rangle$$

Expand in $1/O(m_b)$

- relate QCD currents to Heavy Quark Effective Theory (HQET) currents
- expand HQET operators in $1/Q, Q = m_b, \sqrt{q^2}$

Result

- systematic approach, model independent
- amplitudes incl. corrections of order $m_c^2/Q^2, \alpha_s,\ Q = m_b, \sqrt{q^2}$
- $\Lambda_{\mathrm{QCD}}/m_b$ corrections parametrically suppressed

Observables at Low Recoil (I)

- all observables can be expressed in terms of transversity amplitudes (TAs): A_i^a, $i =$ K^* polarization , $a = L, R$
- at Low Recoil the short distance contributions **factorize** at LO:

$$A_i^a = f_i \times \rho^a$$

- f_i contain long distance (LD) contributions only
- $\rho^{L,R}$ contain short distance (SD) coefficients $\mathcal{C}_i$ only
- 6 TAs, but only 2 combinations of SD coefficients and multitude of observables
- $\Rightarrow$ system is heavily overconstrained by observables
- $\Rightarrow$ reduced complexity wrt. Large Recoil

Observables at Low Recoil (II)

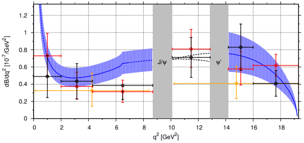
at Low Recoil, all observables are functions of only two SD coefficients

- decay rate $\mathrm{d}\mathcal{B}/\mathrm{d}q^2 \propto \rho_1 \times$ form factor terms
- forward-backward asymmetry $A_{\mathrm{FB}}(q^2) \propto \rho_2/\rho_1 \times$ form factor terms
- fraction $F_{\mathrm{L}}(q^2)$ of longitudinally polarized K^* is independent of SD coefficients at leading order! Tests form factors.

all of these have been measured by BaBar ('06,'08), Belle ('09) and CDF ('09-'10).

New Precision Observables at Low Recoil

- form factors are biggest source of theoretical uncertainties
- construct observables which are independent of form factors, e.g.



$$H_T^{(2)} = \frac{\sqrt{2}J_4}{\sqrt{-J_2^c(2J_2^s - J_3)}} = 2\frac{\rho_2}{\rho_1} = \text{SD only}$$

- $H_T^{(2)}$ provides identical information as $A_{\mathrm{FB}} \propto \rho_2/\rho_1$ but theoretical uncertainty is much smaller!
- SM prediction at Low Recoil:

$$\langle A_{\mathrm{FB}} \rangle = -0.41 \pm 0.073 \qquad (17\%)$$
$$\left\langle H_T^{(2)} \right\rangle = -0.972 \pm 0.010 \qquad (1\%)$$

$H_T^{(1,2,3)}$ not measured yet, probably need full angular analysis!
$\Rightarrow$ LHCb, SuperBelle volunteers wanted!

Model Independent Analysis

$$\mathcal{H}^{\rm eff} = -\frac{4G_{\rm F}}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i \mathcal{C}_i(\mu)\mathcal{O}_i(\mu) + O\left(V_{ub}V_{us}^*\right)$$

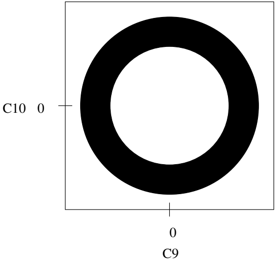
$$\mathcal{O}_7 \propto [\bar{s}\sigma_{\mu\nu}P_R b]F^{\mu\nu} \qquad\qquad \mathcal{O}_{9(10)} \propto [\bar{s}\gamma_\mu P_L b][\bar{\ell}\gamma^\mu(\gamma_5)\ell]$$

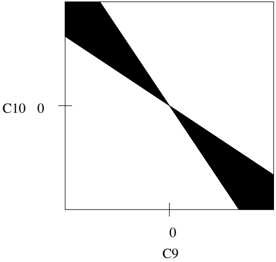
- calculate long distance physics via operators $\mathcal{O}_i(\mu = m_b)$
- treat $\mathcal{C}_i(\mu = m_b)$ as free parameters, $i = (7), 9, 10$
- search for best fit-solutions in the $\mathcal{C}_i$ parameter space
- $|\mathcal{C}_7|$ constrained by existing $\mathcal{B}(b \to s\gamma)$ data: $|\mathcal{C}_7| \simeq |\mathcal{C}_7^{\rm SM}|$
- fit $\mathcal{C}_{9,10}$ from existing $B \to K^*\ell^+\ell^-$ and $B \to X_s\ell^+\ell^-$ data

Model Independent Analysis – Constraining Power

only two types of constraints at Low Recoil:

- decay rate constrains **radius** in $\mathcal{C}_9 - \mathcal{C}_{10}$ plane
- FB-asymmetry constrains **polar angle** in $\mathcal{C}_9 - \mathcal{C}_{10}$ plane
- complementary constraints from a single decay

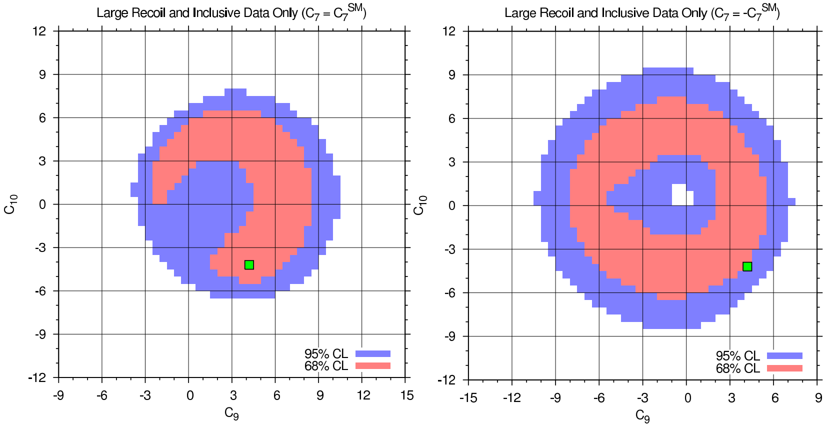




Model Independent Analysis – Large Recoil + Inclusive Constraints

$\mathcal{C}_9$ vs $\mathcal{C}_{10}$. Green square marks the SM.

$\mathcal{C}_7 = +\mathcal{C}_7^{\rm SM}$ $\mathcal{C}_7 = -\mathcal{C}_7^{\rm SM}$



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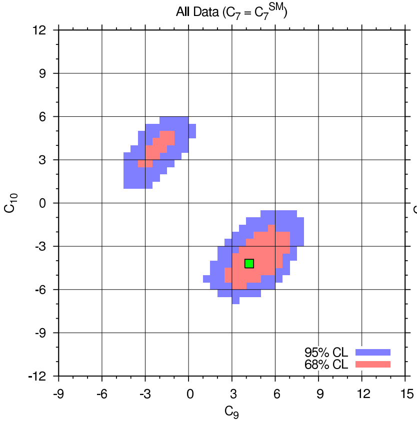
Sources: Belle + CDF data at Large Recoil, and BaBar + Belle data of $\bar{B} \to X_s \ell^+ \ell^-$

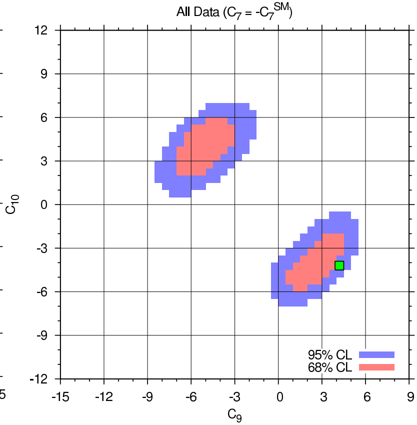
Model Independent Analysis – Global Constraints (incl. Low Recoil)

$\mathcal{C}_9$ vs $\mathcal{C}_{10}$. Green square marks the SM.

$$\mathcal{C}_7 = +\mathcal{C}_7^{\mathrm{SM}}$$



$$\mathcal{C}_7 = -\mathcal{C}_7^{\mathrm{SM}}$$



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Sources: Belle + CDF data at Large and Low Recoil, and BaBar + Belle data of $\bar{B} \to X_s \ell^+\ell^-$

Conclusion and Outlook

Conclusion

- calculated observables of $\bar{B} \to \bar{K}^* \ell^+ \ell^-$ at Low Recoil
- increased usage of available (and future) data
- find stronger and complementary constraints on $\mathcal{C}_i$ than from Large Recoil and/or inclusive decays alone
- provides access to form factors via short distance-independent observables

Outlook

- scan for complex valued $\mathcal{C}_i$ from CP asymmetries (work in progress, C.Bobeth, G.Hiller, DvD)

Literature

Literature on this decay includes (amongst others)

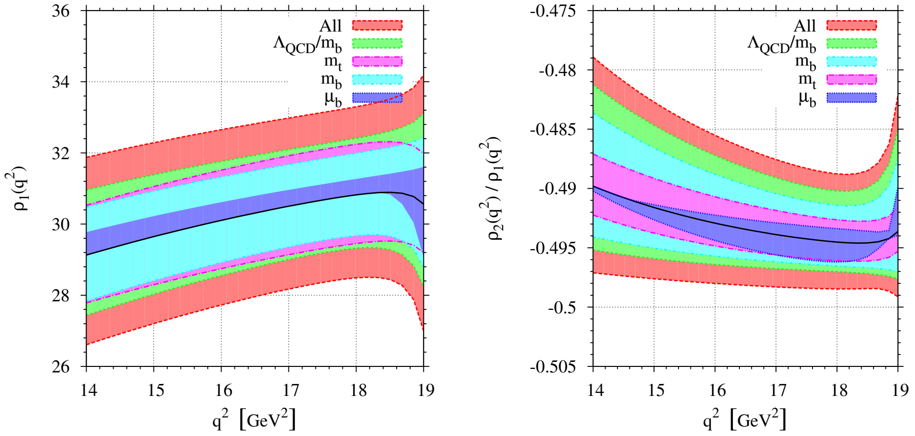
- NLO calculation at Large Recoil (M.Beneke, T.Feldmann, D.Seidel '01 and '04): `arxiv:hep-ph/0106067` and `arxiv:hep-ph/0412400`
- Expansion in Λ/Q, $Q = m_b, \sqrt{q^2}$ (B.Grinstein, D.Pirjol '04): `arxiv:hep-ph/0404250`
- Low Recoil observables and model independent analysis (C.Bobeth, G.Hiller, DvD '10): `arxiv:1006.5013 [hep-ph]`

Outline

Backup Slides

Short Distance Coefficients

q^2 spectrum + uncertainty of SD coefficients



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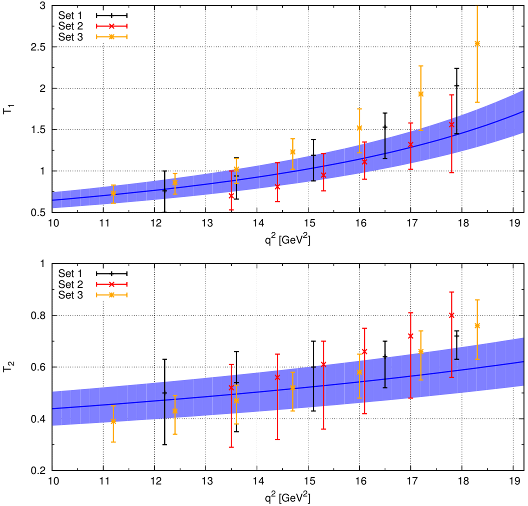
Lattice Data vs Light Cone Sum Rules

Lattice data sets: D.Becirevic, V.Lubicz, F.Mescia '06 LCSR FF: P.Ball, R.Zwicky '04



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SM Values of Wilson Coefficients

- Inputs: α_s, m_t, M_W and θ_W at matching scale $\mu_0 = O(M_W)$.
- At $\mu = m_b \simeq 4.8$ GeV to NNLL:

$\mathcal{C}_1$	-0.257	$\mathcal{C}_6$	$+0.001$
$\mathcal{C}_2$	$+1.009$	$\mathcal{C}_7$	-0.298
$\mathcal{C}_3$	-0.005	$\mathcal{C}_8$	-0.164
$\mathcal{C}_4$	-0.078	$\mathcal{C}_9$	$+4.211$
$\mathcal{C}_5$	<0.001	$\mathcal{C}_{10}$	-4.103

Short Distance Couplings at Low Recoil

There are only two independent bilinear combinations of the $\mathcal{C}_i$:

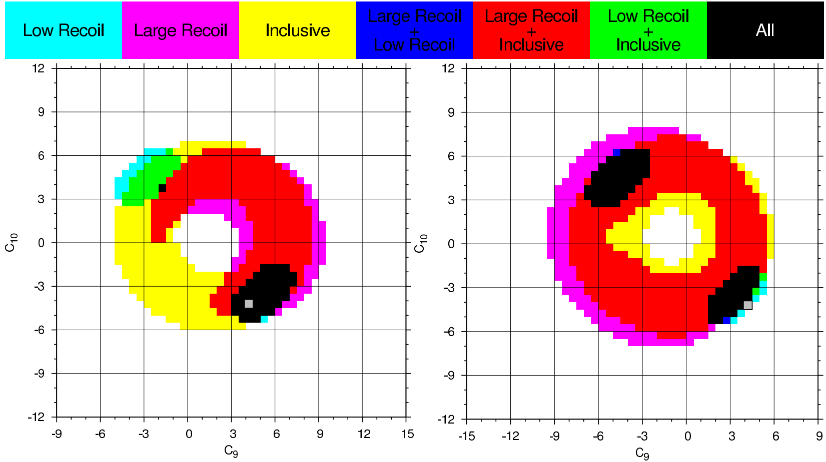
$$\rho_1 = \left|\mathcal{C}_9^{\text{eff}} + \kappa \frac{2 m_b m_B}{q^2} \mathcal{C}_7^{\text{eff}}\right|^2 + |\mathcal{C}_{10}|^2$$

$$\rho_2 = \mathrm{Re}\left\{ \left(\mathcal{C}_9^{\text{eff}} + \kappa \frac{2 m_b m_B}{q^2} \mathcal{C}_7^{\text{eff}}\right) \mathcal{C}_{10}^* \right\}$$

with $\kappa \equiv \kappa(\mu) = 1 + O(\alpha_s^2)$ for $\mu = m_b(m_b)$.

Model Independent Analysis – Individual Constraints

$\mathcal{C}_9$ vs $\mathcal{C}_{10}$. Grey square marks the SM.



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Transverse Asymmetries

Transverse asymmetries $A_T^{(i)}$, $i = 2, 3, 4$

- $i = 1$ discouraged and $i = 2, 3, 4$ proposed by U.Egede et al '08
- Tailored for $\mathcal{C}_7'$ sensitivity at Large Recoil

Large Recoil

$O(1)$, with resonant like structure at/near the zero-crossing of A_{FB}.

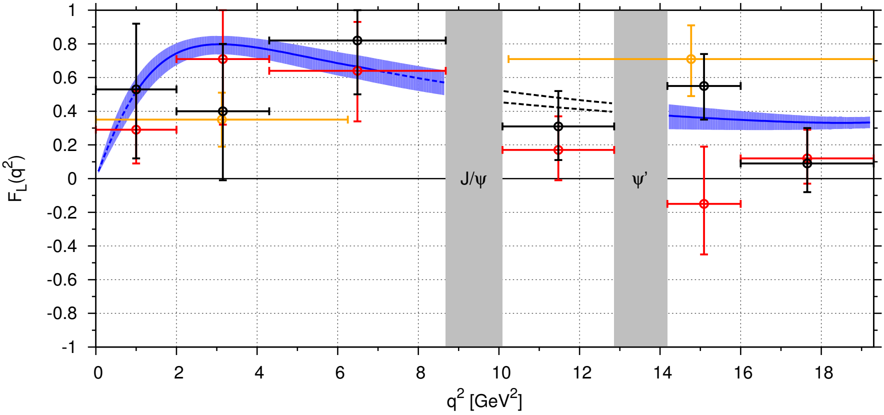
Low Recoil

Not $O(1)$! Very different behaviour than at Large Recoil. In the limit $q^2 \to q^2_{\max}$: $A_T^{(i)} \to -1, +\infty, 0$ for $i = 2, 3, 4$, respectively.

$F_{\mathrm{L}}(B \to K^* \ell^+ \ell^-), \ell = e, \mu$

SM Result for F_{L}

Exp. Data: BaBar'08, Belle'09, CDF'09



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