$b \to s + \bar{\ell}\ell \; (\bar{\nu}\nu)$ DECAYS @ HIGH-q^2

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XVII SuperB Workshop and Kick Off meeting

La Biodola - Elba

OUTLINE

1) Effective theory (EFT) of $\Delta B = 1$ FCNC decays
   A) In the Standard Model (SM)
   B) Beyond the SM (BSM)
2) Exclusive $(B \to K + \bar{\nu}\nu)/(B \to K + \bar{\ell}\ell)$
3) Exclusive $B \to V_{on-shell}(\to P_1 P_2) + \bar{\ell}\ell$
   A) Kinematics and observables in angular distribution
   B) Experimental results (BaBar, Belle, CDF)
   C) $\bar{c}c$-backgrounds and q^2-regions
   D) High-q^2: theory + phenomenology

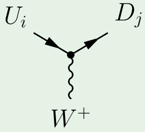
EFT of $\Delta B = 1$ decays in SM and beyond

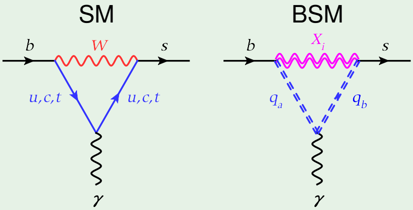
FCNC DECAYS IN THE SM

FLAVOUR CHANGING NEUTRAL CURRENT: $D_i \to D_j$ (AND $U_i \to U_j$)

$U_i = \{u, c, t\}, \quad Q_U = +2/3$

$D_j = \{d, s, b\}, \quad Q_D = -1/3$

$\mathcal{L}_{\text{SM}-\text{FC}} \sim$  $\sim V_{ij}^{\text{CKM}}$



FCNC processes in the SM are

- quantum fluctuations = loop-supressed

  $\to$ no suppression of BSM contributions wrt SM

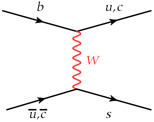
  $\to$ indirect search for BSM signals
- strong scale hierarchy among external and internal scales in FCNC B decays

$$\Longrightarrow \quad (m_b \approx 5\,\text{GeV}) \ll (M_W \approx 80\,\text{GeV})$$

$\Delta B = 1$ EFT IN THE SM (FOR $b \to s$)

I) decoupling (OPE) of heavy particles ($W, Z, t, \ldots$) @ EW scale: $\mu_{EW} \gtrsim M_W$
$\to$ factorisation into short-distance: C_i and long-distance: $\mathcal{O}_i$

II) RG-running to lower scale: $\mu_b \sim m_b \to$ resums large log's: $[\alpha_s \ln(\mu_b/\mu_{EW})]^n$



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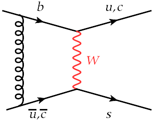
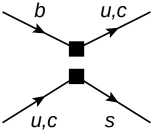
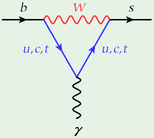
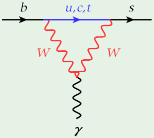


$\longrightarrow \quad C_{1,2}^{(0)} + \frac{\alpha_s}{4\pi} C_{1,2}^{(1)} \quad \times$

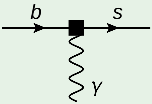


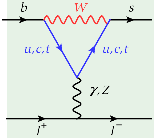
MOST RELEVANT FOR $b \to s + \bar{\ell}\ell$

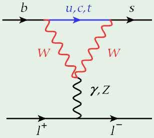


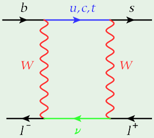


$\longrightarrow \quad C_7^{\gamma} \quad \times$

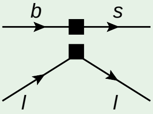








$\longrightarrow \quad C_{9,10}^{\ell\ell} \quad \times$



SM operator List

. . . using CKM unitarity

$$\mathcal{L}_{\rm SM} \sim \frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left(\mathcal{L}_{\rm SM}^{(t)} + \hat{\lambda}_u \, \mathcal{L}_{\rm SM}^{(u)} \right), \qquad \hat{\lambda}_u = V_{ub} V_{us}^* / V_{tb} V_{ts}^*$$

$$\mathcal{L}_{\rm SM}^{(u)} = C_1(\mathcal{O}_1^c - \mathcal{O}_1^u) + C_2(\mathcal{O}_2^c - \mathcal{O}_2^u)$$

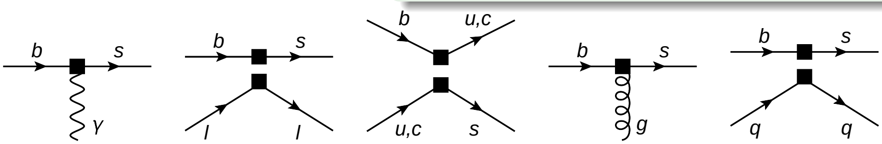
$\mathcal{O}_{1,2}^{u,c}$ = curr.-curr.: $b \to s\,\{\bar{u}u,\ \bar{c}c\}$

$\Rightarrow$ CP-violation in the SM is tiny

$$\mathrm{Im}[\hat{\lambda}_u] \approx \lambda^2 \bar{\eta} \sim 10^{-2}$$

$$\mathcal{L}_{\rm SM}^{(t)} = C_1 \mathcal{O}_1^c + C_2 \mathcal{O}_2^c + \sum_{i>2} C_i \mathcal{O}_i$$

$\mathcal{O}_7^\gamma$	= electr.magn.	$b \to s\,\gamma$
$\mathcal{O}_{9,10}^{\ell\ell}$	= semi-lept.	$b \to s\,\bar{\ell}\ell$
$\mathcal{O}_{1,2}^c$	= curr.-curr.	$b \to s\,\bar{c}c$
$\mathcal{O}_8^g$	= chromo.magn.	$b \to s\,g$
$\mathcal{O}_{3,4,5,6}$	= QCD-peng.	$b \to s\,\bar{q}q$, $q = \{u, d, s, c, b\}$
$\mathcal{O}_{3,4,5,6}^Q$	= QED-peng.	$b \to s\,\bar{q}q$, $q = \{u, d, s, c, b\}$
$\mathcal{O}_b$	= QED-box	$b \to s\,\bar{b}b$



General approach beyond SM ...

MODEL-DEP. 1) decoupling of new heavy particles @ NP scale: $\mu_{NP} \gtrsim M_W$

2) RG-running to lower scale $\mu_b \sim m_b$ (potentially tower of EFT's)

MODEL-INDEP. extending SM EFT-Lagrangian $\to \ldots$

... beyond the SM:

- $\Rightarrow$??? ... additional light degrees of freedom ($\Leftarrow$ not pursued in the following)
- $\Rightarrow$ ΔC_i ... NP contributions to SM C_i
- $\Rightarrow$ $\sum_{\rm NP} C_j \mathcal{O}_j(???)$ ... NP operators (e.g. $C'_{7,9,10}$, $C^{(\prime)}_{S,P}$, ...)

$$\mathcal{L}_{\rm EFT}(\mu_b) = \mathcal{L}_{\rm QED\times QCD}(u,d,s,c,b,\ e,\mu,\tau,\ ???) + \frac{4G_F}{\sqrt{2}} V_{\rm CKM} \sum_{\rm SM} (C_i + \Delta C_i)\mathcal{O}_i + \sum_{\rm NP} C_j \mathcal{O}_j(???)$$

BEYOND THE SM OPERATOR LIST

frequently considered in model-(in)dependent searches

$b \to s + \bar{\ell}\ell$

$$\mathcal{O}_{7',8'}^{\gamma,g} = \frac{(e, g_s)}{16\pi^2} m_b [\bar{s}\,\sigma_{\mu\nu} P_L (T^a)\, b](F, G^a)^{\mu\nu}, \qquad \mathcal{O}_{9',10'}^{\ell\ell} = \frac{\alpha_e}{4\pi} [\bar{s}\,\gamma^\mu P_R\, b][\bar{\ell}\,(\gamma^\mu, \gamma^\mu\gamma_5)\,\ell],$$

$$\mathcal{O}_{S,S'}^{\ell\ell} = \frac{\alpha_e}{4\pi} [\bar{s}\, P_{R,L}\, b][\bar{\ell}\,\ell], \qquad \mathcal{O}_{P,P'}^{\ell\ell} = \frac{\alpha_e}{4\pi} [\bar{s}\, P_{R,L}\, b][\bar{\ell}\,\gamma_5\,\ell],$$

$$\mathcal{O}_{T}^{\ell\ell} = \frac{\alpha_e}{4\pi} [\bar{s}\,\sigma_{\mu\nu}\, b][\bar{\ell}\,\sigma^{\mu\nu}\,\ell], \qquad \mathcal{O}_{TE}^{\ell\ell} = \frac{\alpha_e}{4\pi}\, i\,\varepsilon^{\mu\nu\alpha\beta} [\bar{s}\,\sigma_{\mu\nu}\, b][\bar{\ell}\,\sigma_{\alpha\beta}\,\ell],$$

- new Dirac-structures beyond SM: right-handed currents, (pseudo-) scalar and/or tensor interactions
- usually added to $\mathcal{L}_{\rm SM}^{(t)}$

$\Rightarrow$ EFT starting point for calculation of observables
!!! Non-PT input required when evaluating matrix elements

Exclusive

$$(B \to K + \bar{\nu}\nu)/(B \to K + \bar{\ell}\ell)$$

$\bar{B} \to \bar{K} + \{\bar{\ell}\ell,\ \bar{\nu}\nu\}$ MATRIX ELEMENT

SM operator basis only

$b \to s + \bar{\nu}\nu$: $\quad \mathcal{L}^{\rm eff} \sim G_F \alpha_e\, V_{tb} V_{ts}^*\ C_L^\nu [\bar{s}\,\gamma_\mu P_L\, b][\bar{\nu}\,\gamma^\mu P_L\,\nu]$

$$\mathcal{M}[\bar{B} \to \bar{K}\bar{\nu}\nu] \propto G_F \alpha_e\, V_{tb} V_{ts}^*\ f_+(q^2)\ C_L^\nu [\bar{\nu}\,\gamma_\mu P_L\,\nu]$$

$$\mathcal{M}[\bar{B} \to \bar{K}\bar{\ell}\ell] \propto G_F \alpha_e\, V_{tb} V_{ts}^*\ f_+(q^2) \left(F_V\, p_B^\mu\, [\bar{\ell}\,\gamma_\mu\,\ell] + F_A\, p_B^\mu\, [\bar{\ell}\,\gamma_\mu \gamma_5\,\ell] + F_P\, m_\ell\, [\bar{\ell}\,\gamma_5\,\ell] \right)$$

$$F_A = C_{10}, \qquad F_V = C_9^{\rm eff} + C_7^{\rm eff} \frac{2 m_b}{M_B + M_K} \frac{f_T}{f_+}, \qquad F_P = C_{10} \left[\frac{(M_B^2 - M_K^2)}{q^2} \left(\frac{f_0}{f_+} - 1 \right) - 1 \right]$$

SM : $\quad C_{10} \approx -4.2, \qquad C_9 \approx 4.2, \qquad C_7 \approx -0.3$

$B \to K$ FORM FACTORS $f_{+,0,T}$

$$\langle K(k)|\bar{s}\,\gamma_\mu\, b|B(p)\rangle = (2p - q)_\mu f_+(q^2) + \frac{M_B^2 - M_P^2}{q^2} q_\mu [f_0(q^2) - f_+(q^2)],$$

$$\langle K(k)|\bar{s}\, i\sigma_{\mu\nu} q^\nu\, b|B(p)\rangle = -[(2p - q)_\mu q^2 - (M_B^2 - M_K^2) q_\mu] \frac{f_T(q^2)}{M_B + M_P}.$$

$(B \to K)$ FF RELATIONS

FF RELATION (ISGUR/WISE) IN HEAVY QUARK LIMIT $m_b \to \infty$

$$f_T = \frac{(M_B + M_K) M_B}{q^2}\, \kappa\, f_+ + \mathcal{O}\left(\frac{\Lambda_{\rm QCD}}{M_B}\right)$$

Grinstein/Pirjol hep-ph/0201298, hep-ph/0404250, $\kappa = 1 + \mathcal{O}(\alpha_s)$: known QCD matching correction

FF RELATION @ $m_b \to \infty$ AND LARGE RECOIL ($E_K \sim M_B$) = LOW-q^2

$$\frac{f_0}{f_+} = \frac{2E_K}{M_B}\left[1 + \mathcal{O}(\alpha_s) + \mathcal{O}\left(\frac{q^2}{M_B^2}\sqrt{\frac{\Lambda_{\rm QCD}}{E_K}}\right)\right],$$

$$\frac{f_T}{f_+} = \frac{M_B + M_K}{M_B}\left[1 + \mathcal{O}(\alpha_s) + \mathcal{O}\left(\sqrt{\frac{\Lambda_{\rm QCD}}{E_K}}\right)\right]$$

$\mathcal{O}(\alpha_s)$: known Beneke/Feldmann hep-ph/0008255,

sub-leading $\Lambda_{\rm QCD}/E_K$: Beneke/Chapovsky/Diehl/Feldmann hep-ph/0206152

Combining $B \to K + \bar{\ell}\ell$ and $B \to K + \bar{\nu}\nu$

Bartsch/Beylich/Buchalla/Gao arXiv:0909.1512 propose ($s = q^2/M_B^2$)

$$R_{25} \equiv \frac{\int_0^{0.25} ds\, d\mathcal{B}[B^- \to K^- \bar{\nu}\nu]/ds}{\int_0^{0.25} ds\, d\mathcal{B}[B^- \to K^- \bar{\ell}\ell]/ds}$$

$$R_{256} \equiv \frac{\int_0^{s_m} ds\, d\mathcal{B}[B^- \to K^- \bar{\nu}\nu]/ds}{\int_0^{0.25} ds\, d\mathcal{B}[B^- \to K^- \bar{\ell}\ell]/ds + \int_{0.6}^{s_m} ds\, d\mathcal{B}[B^- \to K^- \bar{\ell}\ell]/ds}$$

with $s = 0.6 \to q^2 = 16.7\ \text{GeV}^2$ and $s_m = 0.821 \to q^2 = 22.9\ \text{GeV}^2$

SM predictions [arXiv:0909.1512]

$$R_{25} = 7.60^{+0.00}_{-0.00}(a_0)^{+0.00}_{-0.00}(b_1)^{+0.36}_{-0.43}(\mu), \qquad R_{256} = 14.60^{+0.28}_{-0.38}(a_0)^{+0.10}_{-0.02}(b_1)^{+0.62}_{-0.80}(\mu)$$

a_0, b_1 form factor parametrisation, μ renormalisation scale

Most precise SM prediction up to date:

$$Br(B^- \to K^- \bar{\nu}\nu) = R \cdot Br(B^- \to K^- \bar{\ell}\ell)_{exp} = (3.64 \pm 0.47) \cdot 10^{-6}$$

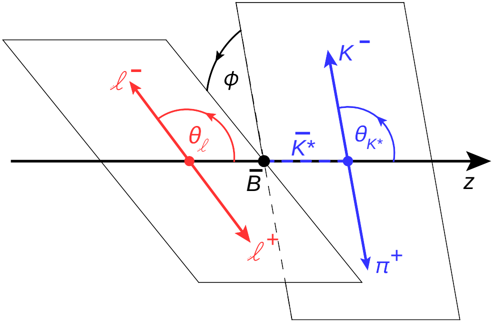
possible strategy: fitting q^2 form factor dependence to exp. $B^- \to K^- \bar{\ell}\ell$ spectrum,

using lattice input at particular q_0^2 as normalisation $\to$ prediction for $B^- \to K^- \bar{\nu}\nu$ using $R_{25,256}$

$$B \to V_{on-shell}(\to P_1 P_2) + \bar{\ell}\ell$$

KINEMATICS

- for on-resonance V decays
  $\rightarrow$ narrow width approximation
  $\rightarrow$ 4 kinematic variables
  (off-reson. 5 kin. variables)
- $Br(K^* \rightarrow K\pi) \approx 99\,\%$
- $\bar{B}^0 \rightarrow \bar{K}^{*0}(\rightarrow K^-\pi^+, \bar{K}^0\pi^0) + \bar{\ell}\ell$
  and CP-conjugated decay:
  $B^0 \rightarrow K^{*0}(\rightarrow K^+\pi^-, K^0\pi^0) + \bar{\ell}\ell$
- similarly $B_s \rightarrow \phi(\rightarrow K^+K^-) + \bar{\ell}\ell$



$\bar{B}^0(p_B) \rightarrow \bar{K}^{*0}_{on-shell}(p_{K^*})[\rightarrow K^-(p_K) + \pi^+(p_\pi)] \; + \; \bar{\ell}(p_{\bar{\ell}}) + \ell(p_\ell)$

1) $q^2 = m^2_{\bar{\ell}\ell} = (p_{\bar{\ell}} + p_\ell)^2 = (p_B - p_{K^*})^2$ $\qquad 4m^2_\ell \leqslant q^2 \leqslant (M_B - M_{K^*})^2$

2) $\cos\theta_\ell$ with $\theta_\ell \angle(\vec{p}_B, \vec{p}_{\bar{\ell}})$ in $(\bar{\ell}\ell)$-c.m. system $\qquad -1 \leqslant \cos\theta_\ell \leqslant 1$

3) $\cos\theta_{K^*}$ with $\theta_{K^*} \angle(\vec{p}_B, \vec{p}_K)$ in $(K\pi)$-c.m. system $\qquad -1 \leqslant \cos\theta_{K^*} \leqslant 1$

4) $\phi \; \angle(\vec{p}_K \times \vec{p}_\pi, \vec{p}_{\bar{\ell}} \times \vec{p}_\ell)$ in B-RF $\qquad -\pi \leqslant \phi \leqslant \pi$

Angular distribution

Diff. angular distribution

$$\frac{32\pi}{9}\frac{d^4\Gamma}{dq^2\, d\cos\theta_\ell\, d\cos\theta_{K^*}\, d\phi} = I_1^s \sin^2\theta_{K^*} + I_1^c \cos^2\theta_{K^*} + (I_2^s \sin^2\theta_{K^*} + I_2^c \cos^2\theta_{K^*})\cos 2\theta_\ell$$
$$+ I_3 \sin^2\theta_{K^*} \sin^2\theta_\ell \cos 2\phi + I_4 \sin 2\theta_{K^*} \sin 2\theta_\ell \cos\phi + I_5 \sin 2\theta_{K^*} \sin\theta_\ell \cos\phi$$
$$+ (I_6^s \sin^2\theta_{K^*} + I_6^c \cos^2\theta_{K^*})\cos\theta_\ell + I_7 \sin 2\theta_{K^*} \sin\theta_\ell \sin\phi$$
$$+ I_8 \sin 2\theta_{K^*} \sin 2\theta_\ell \sin\phi + I_9 \sin^2\theta_{K^*} \sin^2\theta_\ell \sin 2\phi$$

$I_i^{(k)}(q^2) = q^2$-dependent "ANGULAR OBSERVABLES"

$\Rightarrow 2 \times (12 + 12) = 48$ when measuring separately

A) decay + CP-conjugate decay

B) for each $\ell = e,\ \mu$ (τ's are interesting too!!!)

CP-conjugated decay: $d^4\bar{\Gamma}$ from $d^4\Gamma$ by replacing

$$I_{1,2,3,4,7}^{(k)} \quad\rightarrow\quad +\bar{I}_{1,2,3,4,7}^{(k)}[\delta_W \rightarrow -\delta_W], \qquad \text{CP-even}$$

$$I_{5,6,8,9}^{(k)} \quad\rightarrow\quad -\bar{I}_{5,6,8,9}^{(k)}[\delta_W \rightarrow -\delta_W], \qquad \text{CP-odd}$$

with $\ell \leftrightarrow \bar{\ell} \Rightarrow \theta_\ell \rightarrow \theta_\ell - \pi$ and $\phi \rightarrow -\phi$ and weak phases δ_W conjugated

Observables - I

- for (SM + χ-flipped) operators and $m_\ell = 0$: $I_1^s = 3 I_2^s, \quad I_1^c = -I_2^c, \quad I_6^c = 0$
- in presence of scalar and/or tensor operators: $I_6^c \neq 0$

Combining decay + CP-conjugated decay

CP-averaged $$S_i^{(k)} = \left(I_i^{(k)} + \bar{I}_i^{(k)}\right) \Big/ \frac{d(\Gamma + \bar{\Gamma})}{dq^2}$$

CP asymmetries $$A_i^{(k)} = \left(I_i^{(k)} - \bar{I}_i^{(k)}\right) \Big/ \frac{d(\Gamma + \bar{\Gamma})}{dq^2}$$

- normalisation to CP-ave rate $\rightarrow$ reduce form factor dependence
  BUT better suited normalisations possible (examples later)
- if full angular fit from experimental data possible then

1) $S^{(k)}_{1,2,3,4,7}$ and $A^{(k)}_{5,6,8,9}$ from $d^4(\Gamma + \bar{\Gamma})$ = flavour-untagged B samples

2) $A^{(k)}_{1,2,3,4,7}$ and $S^{(k)}_{5,6,8,9}$ from $d^4(\Gamma - \bar{\Gamma})$

CP-odd (i = 5,6,8,9) $\Rightarrow$ CP-asymmetries $\sim d^4(\Gamma + \bar{\Gamma})$
can be measured from untagged (equally mixed ???) B samples
??? requires knowledge of $\bar{B}/B$-fraction of untagged sample: LHCb vs SuperB

Observables - II

- decay rate
$$\frac{d\Gamma}{dq^2} = \frac{3}{4}(2I_1^s + I_1^c) - \frac{1}{4}(2I_2^s + I_2^c), \qquad \frac{d\bar{\Gamma}}{dq^2} = \frac{d\Gamma}{dq^2}[I_i^{(k)} \to \bar{I}_i^{(k)}]$$
- rate CP-asymmetry
$$A_{\rm CP} = \frac{d(\Gamma - \bar{\Gamma})}{dq^2} \Big/ \frac{d(\Gamma + \bar{\Gamma})}{dq^2} = \frac{3}{4}(2A_1^s + A_1^c) - \frac{1}{4}(2A_2^s + A_2^c)$$
- lepton forward-backward asymmetry
$$A_{\rm FB} = \left[\int_0^1 - \int_{-1}^0\right] d\cos\theta_\ell \frac{d^2(\Gamma - \bar{\Gamma})}{dq^2\, d\cos\theta_\ell} \Big/ \frac{d(\Gamma + \bar{\Gamma})}{dq^2} = \frac{3}{8}(2S_6^s + S_6^c)$$
- lepton forward-backward CP-asymmetry
$$A_{\rm FB}^{\rm CP} = \left[\int_0^1 - \int_{-1}^0\right] d\cos\theta_\ell \frac{d^2(\Gamma + \bar{\Gamma})}{dq^2\, d\cos\theta_\ell} \Big/ \frac{d(\Gamma + \bar{\Gamma})}{dq^2} = \frac{3}{8}(2A_6^s + A_6^c)$$
- CP-ave. longitudinal and transverse K^* polarisation fractions
$$F_L = -S_2^c, \qquad F_T = 4S_2^s$$

OBSERVABLES - III

- "transversity observables" (designed for low-q^2)

$$A_T^{(2)} = \frac{S_3}{2S_2^s}, \qquad A_T^{(3)} = \sqrt{\frac{4S_4^2 + S_7^2}{-2S_2^c\,(2S_2^s + S^3)}}, \qquad A_T^{(4)} = \sqrt{\frac{S_5^2 + 4S_8^2}{4S_4^2 + S_7^2}}$$

- lepton-flavour e, μ-non-universal (extend to $l_i^{(k)}$!!! SuperB)

$$R_{K^*(X_s,\,K)} = \frac{d\Gamma[B \to K^*\,(X_s,\,K) + \bar{e}e]}{dq^2} \Bigg/ \frac{d\Gamma[B \to K^*\,(X_s,\,K) + \bar{\mu}\mu]}{dq^2}$$

- isospin asymmetry (extend to $l_i^{(k)}$!!! SuperB - only @ low-q^2, @ high-q^2 $\sim 1/m_b^3$)

$$A_I = \frac{(\tau_{B^+}/\tau_{B^0}) \times dBr[B^0 \to K^{*0}\bar{\ell}\ell] - dBr[B^+ \to K^{*+}\bar{\ell}\ell]}{(\tau_{B^+}/\tau_{B^0}) \times dBr[B^0 \to K^{*0}\bar{\ell}\ell] + dBr[B^+ \to K^{*+}\bar{\ell}\ell]}$$

- and others... $A_T^{(5)}$, A_{6s}^{V2s}, A_8^V, $H_T^{(1,2,3)}$...

Measuring Angular Observables

likely that exp. results only in some q^2-integrated bins: $\langle \ldots \rangle = \int_{q^2_{min}}^{q^2_{max}} dq^2 \ldots$,
then use some (quasi-) single-diff. distributions in θ_ℓ, θ_{K^*}, ϕ

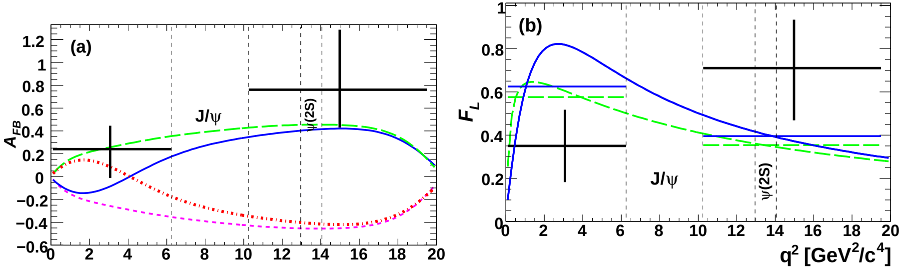
-
$$\frac{d\langle\Gamma\rangle}{d\phi} = \frac{1}{2\pi}\left\{\langle\Gamma\rangle + \langle I_3\rangle \cos 2\phi + \langle I_9\rangle \sin 2\phi\right\}$$

- 2 bins in $\cos\theta_{K^*}$
$$\frac{d\langle A_{\theta_{K^*}}\rangle}{d\phi} \equiv \int_{-1}^{1} d\cos\theta_l \left[\int_0^1 - \int_{-1}^0\right] d\cos\theta_{K^*} \frac{d^3\langle\Gamma\rangle}{d\cos\theta_{K^*}\, d\cos\theta_l\, d\phi}$$
$$= \frac{3}{16}\left\{\langle I_5\rangle \cos\phi + \langle I_7\rangle \sin\phi\right\}$$

- (2 bins in $\cos\theta_{K^*}$) + (2 bins in $\cos\theta_l$)
$$\frac{d\langle A_{\theta_{K^*},\theta_l}\rangle}{d\phi} \equiv \left[\int_0^1 - \int_{-1}^0\right] d\cos\theta_l \frac{d^2\langle A_{\theta_{K^*}}\rangle}{d\cos\theta_l\, d\phi} = \frac{1}{2\pi}\left\{\langle I_4\rangle \cos\phi + \langle I_8\rangle \sin\phi\right\}$$

BaBar [arXiv:0804.4412]

Analysis of 384 M $B\bar{B}$ pairs $\longrightarrow$ search all channels $B^{+,0}$, $K^{(*),+,-}$ and $\ell = e,\ \mu$



- 2 bins: low-$q^2 \in [0.1 - 6.25]$ GeV^2 and high-$q^2 > 10.24$ GeV^2

  $$\Rightarrow (27 \pm 6) + (37 \pm 10) = 64 \text{ events}$$

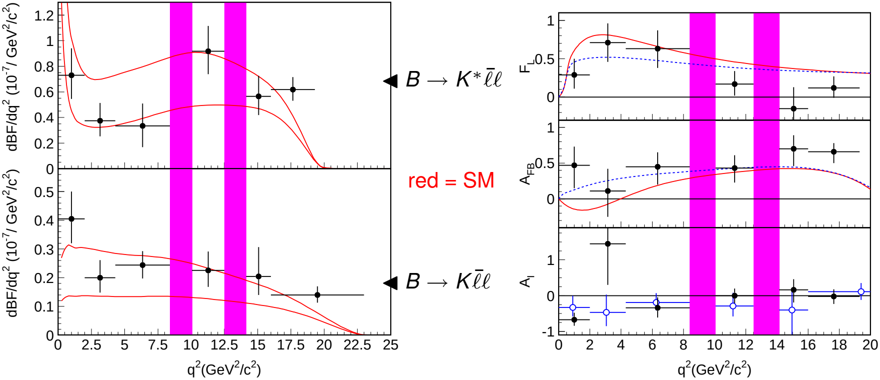
- veto of J/ψ and ψ' regions: background $B \to K^*(\bar{c}c) \to K^*\bar{\ell}\ell$
- angular analysis in each q^2-bin in θ_ℓ and θ_{K^*} $\Rightarrow$ fit F_L and $A_{\rm FB}$

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_{K^*}} = \frac{3}{2}F_L\cos^2\theta_{K^*} + (1 - F_L)(1 - \cos^2\theta_{K^*}),$$

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_{\ell}} = \frac{3}{4}F_L(1 - \cos^2\theta_\ell) + \frac{3}{8}(1 - F_L)(1 + \cos^2\theta_\ell) + A_{\rm FB}\cos\theta_\ell$$

BELLE [ARXIV:0904.0770]

Analysis of 657 M $B\bar{B}$ pairs = 605 fb^{-1} $\rightarrow$ search all channels $B^{+,0}$, $K^{(*),+,-}$ and $\ell = e,\ \mu$

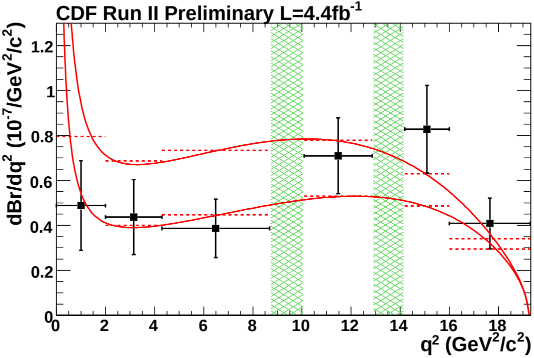


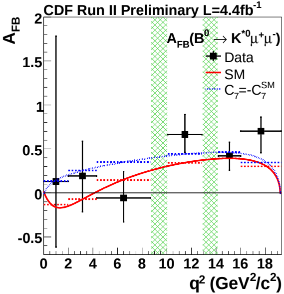
- 6 bins $\Rightarrow$ 247 events (121 @ $q^2 > 14$ GeV^2)
- angular analysis in each q^2-bin in θ_ℓ and θ_{K^*} $\Rightarrow$ fit F_L and $A_{\rm FB}$
- all-q^2 extrapolated results:

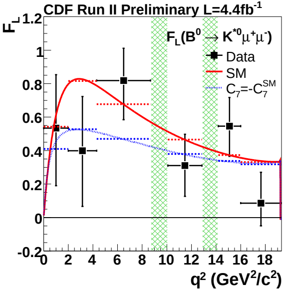
$$Br = (10.7^{+1.1}_{-1.0} \pm 0.09) \times 10^{-7}, \qquad A_{\rm CP} = -0.10 \pm 0.10 \pm 0.01,$$

$$R_{K^*} = 0.83 \pm 0.17 \pm 0.08 \text{ (SM} = 0.75), \qquad A_I = -0.29^{+0.16}_{-0.16} \pm 0.09 \ (q^2 < 8.68 \text{ GeV}^2)$$

- analysis of 4.4 fb^{-1} (CDF Run II) $\Rightarrow$ only $B^0 \to K^{*0}\bar{\mu}\mu$
- discovery of $B_s \to \phi\bar{\mu}\mu$ 6.3 σ (27 ± 6) events
- 101 events (42 @ $q^2 > 14$ GeV^2) - Belle q^2-binning

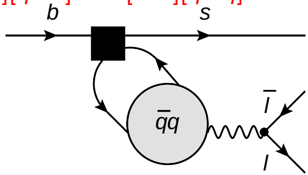






$(\bar{q}q)$-RESONANCE BACKGROUNDS

general theory problem in $b \to s + \bar{\ell}\ell$ due to Op's: $[\bar{s}\Gamma q][\bar{q}\Gamma' b]$ and $[\bar{s}\Gamma b][\bar{q}\Gamma' q]$



LONG DISTANCE - $(\bar{q}q)$-RESONANCE BACKGROUND

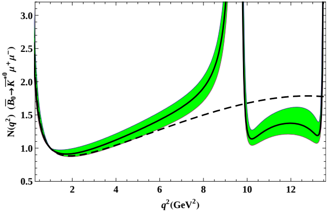
$$\mathcal{A}[B \to V + \bar{\ell}\ell] = \mathcal{A}[B \to V + \bar{\ell}\ell]_{SD-FCNC}$$
$$+ \mathcal{A}[B \to V + (\bar{q}q) \to V + \bar{\ell}\ell]_{LD}$$

for $B \to K^* + \bar{\ell}\ell$ $\quad (q^2_{max} \approx 19.2\ \text{GeV}^2)$:

$q = u, d, s$ light resonances below $q^2 \leqslant 1$ GeV^2

suppr. by small QCD-peng. Wilson coeff. or CKM $\hat{\lambda}_u$

$q = c$ start @ $q^2 \sim (M_{J/\psi})^2 \approx 9.6$ GeV^2, $(M_{\psi'})^2 \approx 13.6$ GeV^2



Khodjamirian/Mannel/Pivovarov/Wang arXiv:1006.4945

- OPE near light-cone incl. soft-gluon emission (non-local operator)
- up to 15% in rate for $1 < q^2 < 6$ GeV^2

$\Rightarrow$ should be included in future analysis

q^2 - REGIONS

K^*-energy in B-rest frame: $E_{K^*} = (M_B^2 + M_{K^*}^2 - q^2)/(2M_B)$

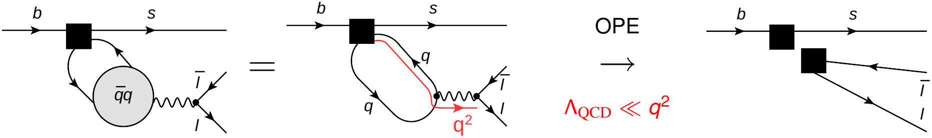
q^2-region	low-q^2 $q^2 \ll M_B^2$	high-q^2 $q^2 \sim M_B^2$
K^*-recoil	large recoil $E_{K^*} \sim M_B/2$	low recoil $E_{K^*} \sim M_{K^*} + \Lambda_{\rm QCD}$
theory preferes method	$q^2 \in [1, 6]$ GeV^2 QCDF, SCET	$q^2 \gtrsim (14 \ldots 15)$ GeV^2 OPE (+ HQET)

low-q^2 above $q = u, d, s$ resonances and below $q = c$ resonances:
$\mathcal{A}[B \to V + (\bar{q}q) \to V + \bar{\ell}\ell]_{LD}$ treated within $(\Lambda_{\rm QCD}/m_c)^2$ expansion

high-q^2 quark-hadron duality + OPE (+ HQET)

HIGH-q^2: OPE – I

Hard momentum transfer $(q^2 \sim M_B^2)$ through $(\bar{q}q) \to \bar{\ell}\ell$ allows local OPE



$$\mathcal{M}[\bar{B} \to \bar{K}^* + \bar{\ell}\ell] \sim \frac{8\pi^2}{q^2} i \int d^4x\, e^{iq\cdot x} \langle \bar{K}^* | T\{\mathcal{L}^{\rm eff}(0), j_\mu^{\rm em}(x)\} | \bar{B}\rangle \, [\bar{\ell}\gamma^\mu \ell]$$

$$= \left(\sum_a C_{3a} Q_{3a}^\mu + \sum_b C_{5b} Q_{5b}^\mu + \sum_c C_{6c} Q_{6c}^\mu + \mathcal{O}(dim > 6) \right) [\bar{\ell}\gamma_\mu \ell]$$

Buchalla/Isidori hep-ph/9801456, Grinstein/Pirjol hep-ph/0404250, Beylich/Buchalla/Feldmann arXiv:1101.5118

Leading $dim = 3$ operators: $\langle \bar{K}^* | Q_{3,a} | \bar{B}\rangle \sim$ usual $B \to K^*$ form factors $V, A_{0,1,2}, T_{1,2,3}$

$$Q_{3,1}^\mu = \left(g^{\mu\nu} - \frac{q^\mu q^\nu}{q^2} \right) [\bar{s}\,\gamma_\nu (1 - \gamma_5)\, b] \quad \to \quad C_9 \to C_9^{\rm eff}, \quad (V, A_{0,1,2})$$

$$Q_{3,2}^\mu = \frac{i m_b}{q^2} q_\nu \, [\bar{s}\,\sigma_{\nu\mu} (1 + \gamma_5)\, b] \quad \to \quad C_7 \to C_7^{\rm eff}, \quad (T_{1,2,3})$$

HIGH-q^2: OPE – II

dim = 3	α_s matching corrections are also known
$m_s \neq 0$	2 additional *dim* = 3 operators, suppressed with $\alpha_s m_s / m_b \sim 0.5$ %, NO new form factors
dim = 4	absent
dim = 5	suppressed by $(\Lambda_{\rm QCD}/m_b)^2 \sim 2$ %, explicite estimate @ $q^2 = 15$ GeV^2: $< 1\%$ [Beylich/Buchalla/Feldmann arXiv:1101.5118]
dim = 6	suppressed by $(\Lambda_{\rm QCD}/m_b)^3 \sim 0.2$ % and small QCD-penguin's: $C_{3,4,5,6}$ spectator quark effects: from weak annihilation
BEYOND OPE	duality violating effects [Beylich/Buchalla/Feldmann arXiv:1101.5118]

- based on Shifman model for *c*-quark correlator + fit to recent BES data
- ± 2 % for integrated rate $q^2 > 15$ GeV^2

$\Rightarrow$ exclusive $\bar{B} \to \bar{K}^*(\bar{K}) + \bar{\ell}\ell$ under good theoretical control !!!

BUT, still missing $B \to K^*$ form factors @ high-q^2
for predictions of angular observables $I_i^{(k)}$

HIGH-q^2: OPE + HQET – I

Framework developed by Grinstein/Pirjol hep-ph/0404250

1) OPE in $\Lambda_{\rm QCD}/Q$ with $Q = \{m_b, \sqrt{q^2}\}$ + matching on HQET + expansion in m_c

$$\mathcal{M}[\bar{B} \to \bar{K}^* + \bar{\ell}\ell] \sim \frac{8\pi}{q^2} \sum_{i=1}^{6} C_i(\mu)\, \mathcal{T}_\alpha^{(i)}(q^2, \mu)\, [\bar{\ell}\gamma^\alpha \ell]$$

$$\mathcal{T}_\alpha^{(i)}(q^2, \mu) = i \int d^4x\, e^{iq\cdot x} \langle \bar{K}^* | T\{\mathcal{O}_i(0), j_\alpha^{\rm em}(x)\} | \bar{B}\rangle = \sum_{k \geqslant -2} \sum_j C_{i,j}^{(k)} \langle \mathcal{Q}_{j,\alpha}^{(k)} \rangle$$

$\mathcal{Q}_{j,\alpha}^{(k)}$	power	$\mathcal{O}(\alpha_s)$
$\mathcal{Q}_{1,2}^{(-2)}$	1	$\alpha_s^0(Q)$
$\mathcal{Q}_{1-5}^{(-1)}$	$\Lambda_{\rm QCD}/Q$	$\alpha_s^1(Q)$
$\mathcal{Q}_{1,2}^{(0)}$	m_c^2/Q^2	$\alpha_s^0(Q)$
$\mathcal{Q}_{j>3}^{(0)}$	${\Lambda_{\rm QCD}}^2/Q^2$	$\alpha_s^0(Q)$
$\mathcal{Q}_i^{(2)}$	m_c^4/Q^4	$\alpha_s^0(Q)$

inlcuded,
unc. estimate by naive pwr cont.

2) HQET FF-relations at sub-leading order + α_s corrections in leading order

$$T_1(q^2) = \kappa\, V(q^2), \qquad T_2(q^2) = \kappa\, A_1(q^2), \qquad T_3(q^2) = \kappa\, A_2(q^2)\frac{M_B^2}{q^2},$$

$$\kappa = \left(1 + \frac{2D_0^{(v)}(\mu)}{C_0^{(v)}(\mu)}\right) \frac{m_b(\mu)}{M_B}$$

can express everything in terms of QCD FF's $V, A_{1,2}$ @ $\mathcal{O}(\alpha_s \Lambda_{\rm QCD}/Q)$!!!

HIGH-q^2 – SM OPERATOR BASIS

ANGULAR OBSERVABLES ($m_\ell = 0$)

$$(2\, I_2^s + I_3) = 2\,\rho_1\, f_\perp^2, \qquad -I_2^c = 2\,\rho_1\, f_0^2, \qquad I_5/\sqrt{2} = 4\,\rho_2\, f_0 f_\perp,$$

$$(2\, I_2^s - I_3) = 2\,\rho_1\, f_\parallel^2, \qquad \sqrt{2}\, I_4 = 2\,\rho_1\, f_0 f_\parallel, \qquad I_6^s/2 = 4\,\rho_2\, f_\parallel f_\perp,$$

$$I_7 = I_8 = I_9 = 0, \qquad (I_6^c = 0)$$

A) ρ_1 and ρ_2 are largely μ-scale independent and B) $f_{\perp,\parallel,0}$ FF-dependent

$$\rho_1 \equiv \left| C_9^{\rm eff} + \kappa \frac{2 m_b^2}{q^2} C_7^{\rm eff} \right|^2 + |C_{10}|^2, \qquad \rho_2 \equiv {\rm Re}\left(C_9^{\rm eff} + \kappa \frac{2 m_b^2}{q^2} C_7^{\rm eff} \right) C_{10}^*$$

Non-PT FF's ("helicity FF's" Bharucha/Feldmann/Wick arXiv:1004.3249)

$$f_\perp = \frac{\sqrt{2\hat\lambda}}{1 + \hat M_{K^*}} V, \qquad f_\parallel = \sqrt{2}\,(1 + \hat M_{K^*})\, A_1, \qquad f_0 = \frac{(1 - \hat s - \hat M_{K^*}^2)(1 + \hat M_{K^*})^2 A_1 - \hat\lambda\, A_2}{2\, \hat M_{K^*} (1 + \hat M_{K^*}) \sqrt{\hat s}}$$

⇒ Assuming validity of LCSR extrapolation Ball/Zwicky [hep-ph/0412079] of $V, A_{1,2}(q^2)$ to $q^2 > 14$ GeV^2 based form factor parametrisation using dipole formula

HIGH-q^2 – "LONG-DISTANCE FREE"

FF-FREE RATIOS !!! TEST SD FLAVOUR COUPLINGS VERSUS EXP. DATA + OPE

$$H_T^{(1)} = \frac{\sqrt{2} I_4}{\sqrt{-I_2^c \left(2 I_2^s - I_3\right)}} = 1$$

$$H_T^{(2)} = \frac{I_5}{\sqrt{-2 I_2^c \left(2 I_2^s + I_3\right)}} = 2\,\frac{\rho_2}{\rho_1}, \qquad H_T^{(3)} = \frac{I_6}{2\sqrt{(2 I_2^s)^2 - I_3^2}} = 2\,\frac{\rho_2}{\rho_1}$$

SM predictions integrated $q^2 \in [14,\ 19.2]$ GeV^2 (CB/Hiller/van Dyk arXiv:1006.5013)

$$\langle H_T^{(1)} \rangle = +0.997 \pm 0.002 \Big|_{\rm FF} {}^{+0.000}_{-0.001} \Big|_{\rm IWR},$$

$$\langle H_T^{(2)} \rangle = -0.972 {}^{+0.004}_{-0.003} \Big|_{\rm FF} \pm 0.001 \Big|_{\rm SL} {}^{+0.008}_{-0.005} \Big|_{\rm IWR} {}^{+0.003}_{-0.004} \Big|_{\rm SD},$$

$$\langle H_T^{(3)} \rangle = -0.958 \pm 0.001 \Big|_{\rm SL} {}^{+0.008}_{-0.006} \Big|_{\rm IWR} {}^{+0.003}_{-0.004} \Big|_{\rm SD}$$

$\langle \ldots \rangle$ = q^2-integration performed in analogy to experimental measurement for each $I_i^{(k)}$ before taking ratio and $\sqrt{\ldots}$

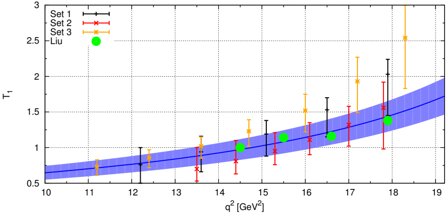
HIGH-q^2 – "SHORT-DISTANCE FREE"

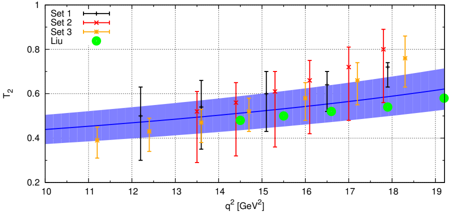
SHORT-DISTANCE-FREE RATIOS

!!! TEST LATTICE VERSUS EXP. DATA + OPE

$$\frac{f_0}{f_\parallel} = \frac{\sqrt{2} I_5}{I_6} = \frac{-I_2^c}{\sqrt{2} I_4} = \frac{\sqrt{2} I_4}{2 I_2^s - I_3} = \sqrt{\frac{-I_2^c}{2 I_2^s - I_3}},$$

$$\frac{f_\perp}{f_\parallel} = \sqrt{\frac{2 I_2^s + I_3}{2 I_2^s - I_3}} = \frac{\sqrt{-I_2^c\,(2 I_2^s + I_3)}}{\sqrt{2} I_4}, \qquad \frac{f_0}{f_\perp} = \sqrt{\frac{-I_2^c}{2 I_2^s + I_3}}$$



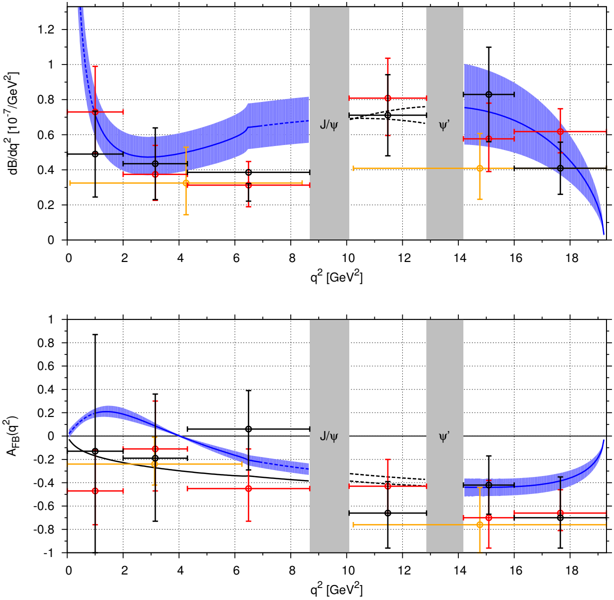


LCSR extrapolation (Ball/Zwicky hep-ph/0412079) of $T_1(q^2)$ and $T_2(q^2)$ to high-q^2 versus quenched Lattice (3 data sets from Becirevic/Lubicz/Mescia hep-ph/0611295)

new unquenced Lattice results to come → Liu/Meinel/Hart/Horgan/Müller/Wingate arXiv:0911.2370, arXiv:1101.2726 no final uncertainty estimate yet

NO lattice results yet for $B \to K^*$ FF's @ high-q^2: V, $A_{0,1,2}$, T_3 !!!

HIGH-q^2 – Br, A_{fb}



Br and A_{FB}

SM prediction + unc. @ low- and high-q^2

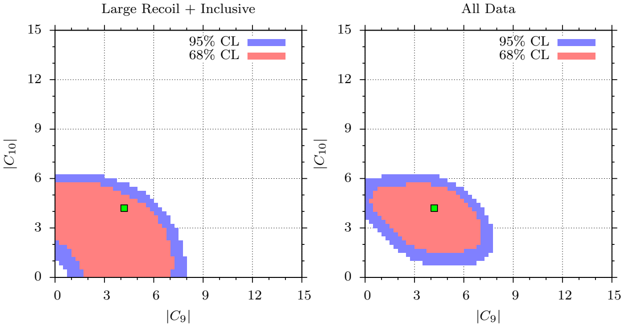
Data points from

[Babar '08]

[Belle '09]

[CDF '10]

"Global" Fit of C_9 and C_{10} – complex



CB/Hiller/van Dyk arXiv:1105.0376

Scan resolution

$|C_7| \in [.30, .35], \quad \Delta|C_7| = .01$

$|C_{9,10}| \in [0, 15], \quad \Delta|C_{9,10}| = 0.25$

$\phi_7 \in [0, 2\pi), \quad \Delta\phi_7 = \pi/16$

$\phi_{9,10} \in [0, 2\pi), \quad \Delta\phi_{9,10} = \pi/16$

SM = green square

- $B \to X_s \bar{\ell}\ell$ Babar/Belle data: Br in ^{2}-bin: $[1, 6]$ GeV^2
- $B \to K^* \bar{\ell}\ell$ Belle/CDF data: Br, $A_{\rm FB}$, F_L in q^2-bin: $[1, 6]$ GeV^2
  Br, $A_{\rm FB}$ in q^2-bins: $[14.2, 16]$ GeV^2 and $[> 16]$ GeV^2

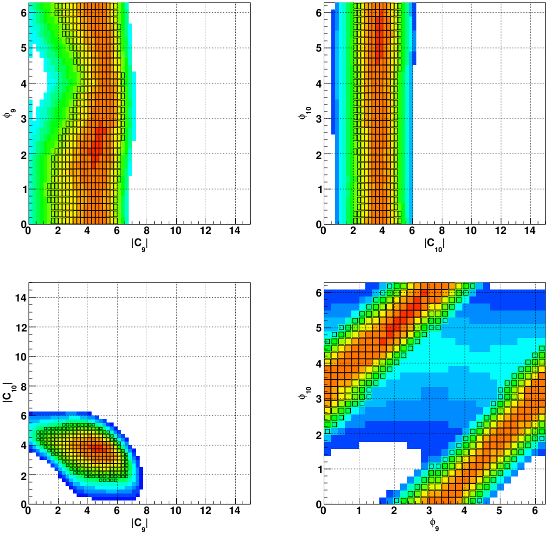
Determining 68 (95) % CL in 6D pmr-space $|C_{7,9,10}|$ and $\phi_{7,9,10}$ $\to$ projection on $|C_9| - |C_{10}|$

$\Rightarrow$ without high-q^2 data [left] and with [right] $\to$ important impact,
BUT form factors from lattice very desireable !!!

$\Rightarrow Br(B_s \to \bar{\mu}\mu) < 1 \cdot 10^{-8}$ @ 95 % CL

Fit $C_{9,10}$ – complex – only Belle data

Model-indep. fit of complex $C_{9,10}$ ($C_9^{\rm SM} = 4.2,\ C_{10}^{\rm SM} = -4.2$)



$B \to K^* \bar{\ell}\ell$

- Br and $A_{\rm FB}$ in q^2-bins

  $[1, 6]$ GeV^2
  $[14.2, 16]$ GeV^2
  $[> 16]$ GeV^2
- F_L in $q^2 \in [1, 6]$ GeV^2

$B \to X_s \bar{\ell}\ell$

- Br in $[1, 6]$ GeV^2

$B \to K \bar{\ell}\ell$

- Br in $[1, 6]$, $[14.2, 16]$, $[> 16]$ GeV^2

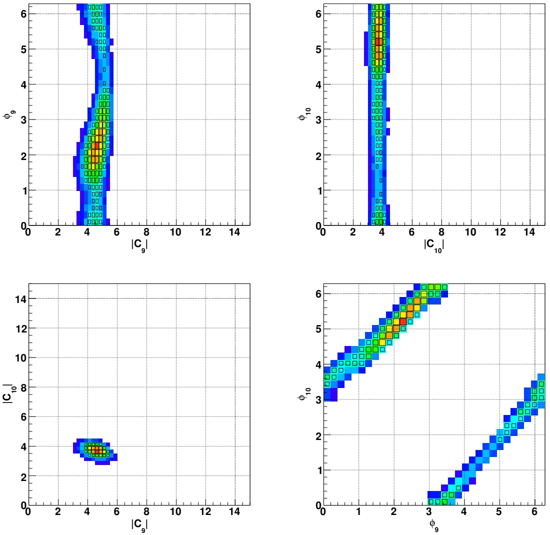
margnialised profile likelihood
95 % (68 % box) CL regions

- ▶ $|C_7| = |C_7^{\rm SM}|$
- ▶ $|C_{9,10}| \in [0, 15]$
- ▶ $\phi_{7,9,10} \in [0, 2\pi)$

preliminary
Beaujean/CB/van Dyk/Wacker

Fit $C_{9,10}$ – complex – Future?

For fun: keep exp. central values, divide all exp. errors by 5



$B \to K^* \bar{\ell}\ell$

- Br and A_{FB} in q^2-bins

  $[1, 6]$ GeV^2
  $[14.2, 16]$ GeV^2
  $[> 16]$ GeV^2

- F_L in $q^2 \in [1, 6]$ GeV^2

$B \to X_s \bar{\ell}\ell$

- Br in $[1, 6]$ GeV^2

$B \to K \bar{\ell}\ell$

- Br in $[1, 6]$, $[14.2, 16]$, $[> 16]$ GeV^2

margnialised profile likelihood 95 % (68 % box) CL regions

- ▶ $|C_7| = |C_7^{\rm SM}|$
- ▶ $|C_{9,10}| \in [0, 15]$
- ▶ $\phi_{7,9,10} \in [0, 2\pi)$

preliminary
Beaujean/CB/van Dyk/Wacker

MORE PHENOMENOLOGY @ HIGH-q^2

CP-asymmetries

- FF-free CP-asymmetries: $a_{\mathrm{CP}}^{(1,2,3)}$ [CB/Hiller/van Dyk arXiv:1105.0376]
- still, theoretical uncertainties large: dominated by renorm. scale μ_b
- a_{CP}^{mix} in $B_s \to \phi(\to K^+K^-) + \bar{\ell}\ell$

Including BSM-operators [work in progress CB/Hiller/van Dyk]

for example, including χ-flipped operators

- extension to $\rho_1 \to \rho_1^{\pm}$
- still have $H_T^{(1)} = 1$
- $I_7 = 0$, but $I_{8,9} \neq 0$
- generalisation: $H_T^{(2)} = H_T^{(3)} = 2\,\frac{\mathrm{Re}(\rho_2)}{\sqrt{\rho_1^- \cdot \rho_1^+}}$
- two new ratios: $H_T^{(4)} = H_T^{(5)} = 2\,\frac{\mathrm{Im}(\rho_2)}{\sqrt{\rho_1^- \cdot \rho_1^+}}$
- $a_{\mathrm{CP}}^{(1)} \to a_{\mathrm{CP}}^{(1,\pm)}$ and $a_{\mathrm{CP}}^{(2)} \to a_{\mathrm{CP}}^{(2,\pm)}$
- additional $a_{\mathrm{CP}}^{(4)}$

Conclusion - I

- rich phenomenology in angular analysis of $B \to V_{on-shell}(\to P_1 P_2) + \bar{\ell}\ell$ to test flavour short-distance couplings – analogously $B_s \to \phi(\to K^+K^-) + \bar{\ell}\ell$
- low-q^2 and high-q^2 regions in $b \to s + \bar{\ell}\ell$ accesible via power exp's (QCDF, SCET, OPE + HQET) $\to$ reveal symmetries of QCD dynamics
- reducing Non-PT uncertainties by suiteable ratios of observables guided by power exp's $\to$ allowing for quite precise theory predictions for exclusive decays
- low-q^2 theoretically well understood (even $(\bar{c}c)$-resonances can be estimated) $\to$ many interesting tests, waiting for data
- high-q^2:
  - $(\bar{c}c)$-resonances seem under control, violation of $H_T^{(1)} = 1$ can be tested
  - "long-distance free" ratios $H_T^{(2,3)}$ to test SM
  - "short-distance free" ratios to test q^2-dep. of FF-ratios directly with lattice
  - need FF input from Lattice $\to$ required to exploit exp. data dBr/dq^2

Dedicated $b \to s\bar{\ell}\ell$ @ high-q^2 Workshop
15.-17. of june 2011, DESY, Hamburg, Germany
http://indico.desy.de/conferenceDisplay.py?confId=4250

CONCLUSION – II

SuperB only

- separate measurement of $\ell = e$ and $\ell = \mu$: investigate ratios of $I_i^{(k)}(\ell = e)/I_i^{(k)}(\ell = \mu)$ in analogy to R_{K^*} @ low- and high-q^2 $\rightarrow$ ℓ-flavour non-universal effects
- isospin asymmetries of angular observables $I_i^{(k)}$ @ low-q^2 ???
  no theoretical study yet, except for branching ratio (Feldmann/Matias hep-ph/0212158)
- measurement of $B \rightarrow (K, K^*) + \bar{\tau}\tau$ feaseable ???
  $\rightarrow$ interesting for BSM scenarios with scalar and pseudo-scalar operators
- combined measurement of $B \rightarrow K + \bar{\nu}\nu$ and $B \rightarrow K + \bar{\ell}\ell$
- $B \rightarrow X_s\bar{\ell}\ell$ @ high-q^2

EOS = new Flavour tool @ TU Dortmund by Danny van Dyk et al.
http://project.het.physik.tu-dortmund.de/eos/
first stable release expected 2011

LITERATURE - INCOMPLETE

- $b \to q + \bar{\ell}\ell$ in QCDF @ low-q^2: Beneke/Feldmann/Seidel hep-ph/0106067, hep-ph/0412400
- $b \to s + \bar{\ell}\ell$ in SCET @ low-q^2: Ali/Kramer/Zhu hep-ph/0601034
- $b \to s + \bar{\ell}\ell$ in OPE + HQET @ high-q^2:
  Grinstein/Pirjol hep-ph/0404250
  Beylich/Buchalla/Feldmann arXiv:1101.5118
- $b \to s + \bar{\ell}\ell$ and $\bar{c}c$-resonances @ low-q^2:
  Buchalla/Isidori/Rey hep-ph/9705253
  Beneke/Buchalla/Neubert/Sachrajda arXiv:0902.4446
  Khodjamirian/Mannel/Pivovarov/Wang arXiv:1006.4945
- $B \to V_{on-shell}(\to P_1 P_2) + \bar{\ell}\ell$
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  Feldmann/Matias hep-ph/0212158 : isospin asymmetry A_I @ low-q^2
  Krüger/Matias hep-ph/0502060 : transv. observables @ low-q^2
  Kim/Yoshikawa arXiv:0711.3880 : @ all-q^2, also $B \to S_{on-shell}(\to P_1 P_2) + \bar{\ell}\ell$
  Bobeth/Hiller/Piranishvili arXiv:0805.2525 : CP asymmetries @ low-q^2
  Egede/Hurth/Matias/Ramon/Reece arXiv:0807.2589 : LHCb and transv. observables @ low-q^2
  Altmannshofer/Ball/Bharucha/Buras/Straub/Wick arXiv:0811.1214 : CP-ave + asy @ low-q^2 + (pseudo-) scalar Op's
  Alok/Dighe/Ghosh/London/Matias/Nagashima/Szynkman arXiv:0912.1382 : $A_{\rm FB}$
  Bharucha/Reece arXiv:1002.4310 : early LHCb potential @ low-q^2
  Egede/Hurth/Matias/Ramon/Reece arXiv:1005.0571 : LHCb and transv. observables@ low-q^2
  Bobeth/Hiller/van Dyk arXiv:1006.5013, arXiv:1105.0376 : @ high-q^2
  Alok et al. arXiv:1008.2367, arXiv:1103.5344 : @ all-q^2 + tensor Op's