New Physics in exclusive $\bar{B}_{d,s} \to \ell^+\ell^-$ and $\bar{B} \to K^{(*)}\ell^+\ell^-$ observables

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FLAVOUR IN THE ERA OF THE LHC
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Approach: Effective theory of $\Delta B = 1$ decays

$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm QED\times QCD}(u, d, s, c, b, e, \mu, \tau, ???)$$

$$+ \frac{4G_F}{\sqrt{2}} V_{\rm CKM} \sum_{\rm SM} (C_i + \Delta C_i)\mathcal{O}_i + \sum_{\rm NP} C_j \mathcal{O}_j$$

$\Rightarrow$??? . . . additional light degrees of freedom ($\Leftarrow$ not pursued)

$\Rightarrow$ ΔC_i . . . NP contributions to SM C_i

$\Rightarrow$ $\sum_{\rm NP} C_j \mathcal{O}_j$ . . . NP operators (**e.g.** $C'_{7,9,10}$**,** $C^{(\prime)}_{S,P}$ . . .)

Classification of observables: in $\bar{B}_{d,s} \to \ell^+\ell^-$ and $\bar{B} \to K^{(*)}\ell^+\ell^-$

searching for NP (ΔC_i and C_j) $\Leftrightarrow$ troublesome hadronic uncertainties

Observables which

1. test the SM: small hadronic uncertainties $<$ few $\%$
2. test NP type: sensitivity to particular type of NP
3. constraint NP: useful to constraint NP parameter space

$\bar{B}_{d,s} \to \ell^+\ell^-$:

uncertainties: $\sim V_{\rm CKM}^2$ and $\sim f_{B_q}^2 \Leftarrow 30\%$

$\Rightarrow$ $\mathcal{B}(\bar{B}_{d,s} \to \ell^+\ell^-)$ $(\ell = \{e, \mu, \tau\})$

SM: $\sim |C_{10}|^2$,

uncert. $\approx 10\%$ (relation to $B_q^0 - \bar{B}_q^0$, works only in SM-op. basis)

NP: $\sim (C_{S,P} - C'_{S,P})$ and $\sim (C_{10} - C'_{10})$

$\Rightarrow$ constraints NP

$\Rightarrow$ $R_{\ell\ell} \equiv \mathcal{B}(B_d \to \ell^+\ell^-)/\mathcal{B}(B_s \to \ell^+\ell^-)$

SM: $\sim |V_{td}/V_{ts}|^2 (f_{B_d}/f_{B_s})^2 \sim \mathcal{O}(10^{-2})$

NP: in MFV $\sim \mathcal{O}(10^{-2})$,

enhancement $\sim \mathcal{O}(1)$ in nonMFV - test of beyond MFV

$\Rightarrow$ tests NP type

$\bar{B} \to K\ell^+\ell^-$ and $\bar{B} \to K^*\ell^+\ell^-$:

1. Backgrounds: $\bar{B} \to K^{(*)}(c\bar{c}) \to K^{(*)}\ell^+\ell^-$

   $\Rightarrow$ low-q^2 = large recoil ($q^2 < M^2_{J/\psi}$)
   high-q^2 ($q^2 > M^2_{\psi'}$)

   for low-q^2 QCDF and SCET applicable !!!

2. hadronic uncertainties = formfactors

   $\bar{B} \to K: \quad f_+, f_0, f_T \quad \longrightarrow \quad \xi_P$ (in low-q^2)

   $\bar{B} \to K^*: \quad V, T_{1,2,3}, A_{0,1,2} \quad \longrightarrow \quad \xi_\perp, \ \xi_\|$

$\Rightarrow$ $d\Gamma(\bar{B} \to K^{(*)}\ell^+\ell^-)/dq^2$

SM: depends on $|C^{\text{eff}}_{7,9,10}|$ and $Re(C^{\text{eff}\,*}_7 C^{\text{eff}}_9)$

NP: sensitive to $C'_{9,10}$, but $C^{(\prime)}_{S,P}$ negligible

low-q^2 QCDF and SCET applicable $\to$ uncertainties: $\pm(25-30)\%$

$\Rightarrow$ constraints NP

$\Rightarrow$ $R_{K^{(*)}} \equiv \int dq^2 \frac{d\Gamma(B \to K^{(*)}\mu^+\mu^-)}{dq^2} \Big/ \int dq^2 \frac{d\Gamma(B \to K^{(*)}e^+e^-)}{dq^2}$

SM: free of hadronic uncertainties: $< \pm 1\%$

NP: sensitive to non-universal couplings to leptons,

$C^{(\prime)}_{S,P}$, neutral Higgs penguins

$\Rightarrow$ tests SM, tests NP type

lepton forward-backward asymmetry

$\Rightarrow$ $A_{\rm FB}(\bar{B} \to K\ell^+\ell^-)$

SM: ~ 0 quasi null test (QED corr. might induce small $A_{\rm FB}$)

NP: $\sim F_S \sim (C_S + C_s')$,

$< 4\%$ for $\ell = \mu$ (negl. C_S') incl. $\bar{B}_s \to \mu^+\mu^-$ (model-indep.),

$< 1\%(30\%)$ for $\ell = \mu$ (τ) in particular MSSM scenarios

$\Rightarrow$ tests NP type

$\Rightarrow$ $dA_{\rm FB}(\bar{B} \to K^*\ell^+\ell^-)/dq^2$ shape and magnitude

SM: depends on $|C_{7,9,10}^{\rm eff}|$,

position of zero q_0^2 has small hadr. uncert. $\lesssim 8\%$

NP: $sgn(C_7^{\rm eff})$, $sgn(C_{10}^{\rm eff})$, Z-penguins and other C_j

low-q^2 QCDF and SCET applicable

$\Rightarrow$ tests SM, constraints NP

K^* angular analysis $\bar{B}^0 \to K^{*0}(\to K^-\pi^+)\ell^+\ell^-$ in low-q^2, using QCDF

$\Rightarrow$ Transverse asymmetries $\mathcal{A}_T^{(1),(2)}$

SM: uncertainties: $< \pm 1\%$ and $< \pm 7\%$
$\Rightarrow$ tests SM

$\Rightarrow$ K^* polarization parameter α_K^*

SM: uncertainties: $\pm 20\%$

$\Rightarrow$ Fractions of K^* polarization $\mathcal{F}_{L,T}$

SM: uncertainties: $< \pm 5\%$ and $< \pm 10\%$
$\Rightarrow$ tests SM

NP: only model-indep. analysis including C_7' available:
$d\mathcal{A}_T^{(1),(2)}/dq^2$ shape depends on $C_7^{(')}$ and pos. of zero sensitive to C_7',
α_K^* and $\mathcal{F}_{L,T}$ $\Rightarrow$ constraints NP

Isospin asymmetry $\frac{dA_I(\bar{B}\to K^*\ell\bar{\ell})}{dq^2} = \frac{d\Gamma(\bar{B}^0\to K^{*0}\ell\bar{\ell})/dq^2 - d\Gamma(\bar{B}^\pm\to K^{*\pm}\ell\bar{\ell})/dq^2}{d\Gamma(\bar{B}^0\to K^{*0}\ell\bar{\ell})/dq^2 + d\Gamma(\bar{B}^\pm\to K^{*\pm}\ell\bar{\ell})/dq^2}$

- sensitive to spectator quark effects: a) annihilation ($\mathcal{O}_{1,\ldots,6}$) and hard spectator scattering b) $\mathcal{O}_8$ and c) $\mathcal{O}_{1,\ldots,6}$
- in low-q^2, using QCDF
- identical to $A_I(\bar{B} \to K^*\gamma)$ for $q^2 \to 0$

SM: $C_{5,6}$ for $q^2 \leq 2\text{GeV}^2$, $C_{3,4}$ for $(2 \leq q^2 \leq 7)\text{GeV}^2$,
uncertainties $\pm 40\%$,
$(2 \leq q^2 \leq 7)\text{GeV}^2$ almost zero (slightly negative $\sim -1\%$)

NP: only MFV mSUGRA analysis available $\to$ sensitive to $sgn(C_7^{\text{eff}})$

$\Rightarrow$ constraints NP

Observable	test SM	test NP type
$\mathcal{B}(\bar{B}_{d,s} \to \ell^+\ell^-)$		
$R_{\ell\ell}$		$\surd$
$d\Gamma(\bar{B} \to K^{(*)}\ell^+\ell^-)/dq^2$		
$R_{K^{(*)}}$	$\surd$	$\surd$
$A_{\rm FB}(\bar{B} \to K\ell^+\ell^-)$		$\surd$
$dA_{\rm FB}(\bar{B} \to K^*\ell^+\ell^-)/dq^2$	$\surd$	
$\mathcal{A}_T^{(1),(2)}$	$\surd$	
α_K^*		
$\mathcal{F}_{L,T}$	$\surd$	
$dA_I(\bar{B} \to K^*\ell^+\ell^-)/dq^2$		