B Decays: Theoretical Overview and Challenges for the LHC

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Outline

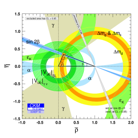
1. Theory I (QCD and SM)
   - Factorization
   - Inclusive *B*-meson decays
   - Exclusive Semi-leptonic *B*-Decays
   - Theory for $B \to K^{(*)}\mu^+\mu^-$ Decays
   - Charmless Non-Leptonic *B*-Decays

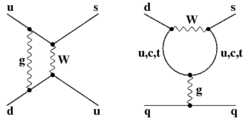
2. Theory II (Phenomenology and NP Models)
   - Right-handed currents
   - *B*-Meson Mixing
   - Rare Semi-Leptonic *B*-Decays

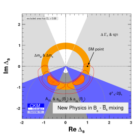
3. Outlook

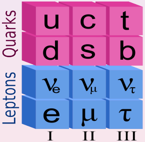
Motivation

- Precision Tests of the CKM Mechanism in the SM
- Sharpening the tools for perturbative and non-perturbative calculations
- Indirect search for New Physics in Rare Decays
- Constraints on Flavour Sector of NP Models









1. Theory I (QCD and SM)

1.1 Factorization

Flavour Transitions induced by Weak Gauge Bosons (or potential NP):

- Weak effective Hamiltonian: $H_{\text{eff}} \propto \sum_i C_i(\mu)\mathcal{O}_i$
- Wilson Coefficients $C_i(m_b)$ in (RG-improved) Perturbation Theory.
  Contain all the information about short-distance dynamics !
- Hadronic Matrix Elements $\langle h_1 h_2 \cdots |\mathcal{O}_i| B\rangle \quad \Rightarrow \quad \ldots$

$\ldots \quad \Rightarrow$ **Treatment of Hadronic Matrix Elements:**

- Reduce to (more) universal quantities, using
  Factorization Theorems based on the Heavy-Quark Expansion:
  - Heavy-quark effective theory (HQET) for small hadronic recoil energy.
  - Soft-collinear effective theory (SCET) for large recoil energy ($\to$ jets).
- (irreducible) Hadronic Parameters (approximately) cancel in certain Ratios:
  - time-dependent CP asymmetry in $B \to J/\psi K_S$
  - isospin-symmetry relations for $B \to \pi\pi$ decays
  - form-factor relations in $B \to K^* \mu^+ \mu^-$
  - ...

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Hadronic Matrix Elements in B-Decays

Theoretical input for:
partial decay rates; CP-, isospin-, FB-, angular asymmetries, ...

- Leptonic decay constants: f_{B,B_s}
- Meson mixing parameters: B_{B,B_s}
- Exclusive transition form factors: $F^{B\to M}(q^2)$
- HQET parameters: m_b, $\frac{\lambda_{1,2}}{m_b}$ ...
- Hadronic light-cone distribution amplitudes: $\phi_\pi(u)$, $\phi_B(\omega)$
- Inclusive shape functions ($\equiv$ PDFs): $S(k)$
- ...

Determination of hadronic matrix elements:

- from Lattice QCD
- from (light-cone) QCD Sum Rules
- from Experiment (on the basis of factorization theorems)

1.2 Inclusive B-meson decays: $B \to X_c \ell\nu$, $B \to X_u \ell\nu$, $B \to X_s\gamma$, ($B \to X_s \ell^+\ell^-$)

Operator Product Expansion (OPE)

- Factorization based on expansion in $1/m_{b,c}$ and $\alpha_s(m_b)$
  - α_s^2 corrections to partonic rate [Melnikov, Czarnecki, Pak]
  - Tree-level expressions known to order $1/m_b^5$; systematics of "intrinsic charm" and "weak annihilation" [Bigi, Breidenbach, TF, Mannel, Turcyzk, Uraltsev, Zwicky,...]

Shape-function region (large recoil energy):

- Factorization theorems in SCET: $d\Gamma = H \cdot J \otimes S$
  - hard coefficient functions H — NNLO [Asatrian et al. 08; Beneke et al. 08; Bell 08]
  - collinear jet function J — NNLO [Becher/Neubert 05/06]
  - soft shape function S (aka PDF) — 2-loop RGE [Becher/Neubert 05]

- Determine: $|V_{cb}|_{\rm incl.} = (41.9 \pm 0.42_{\rm exp} \pm 0.59_{\rm th}) \cdot 10^{-3}$

  Determine: $|V_{ub}|_{\rm incl.} = (4.25 \pm 0.15_{\rm exp} \pm 0.20_{\rm th}) \cdot 10^{-3}$ [Kowalewski@BEAUTY2011]
- NP constraints from $B \to X_s\gamma$ [...; Andersen/Gardi 06; Misiak et al. 07; Becher/Neubert 07; ...]

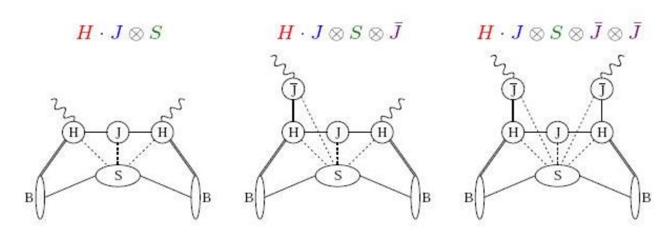
$B \to X_s\gamma$ and Resolved Photon Effects

[Benzke/Lee/Neubert/Paz 09-11]

New effects at sub-leading order in $1/m_b$ expansion:

- Photon does not couple directly to short-distance $b \to s$ transition.

$\Rightarrow$ New Factorization Theorem:



Features of "resolved" photon contribution:

- New jet function $\bar{J}$ in photon direction
- New soft functions from non-local operators with respect to 2 jet directions
- Leading mechanism for CP Violation in the SM: $-0.5\% < \mathcal{A}^{\rm SM}_{X_s\gamma} < 2.8\%$
- Better Null-Tests of the SM: $(\mathcal{A}_{X_s^-\gamma} - \mathcal{A}_{X_s^0\gamma})$ or $\mathcal{A}_{X_{s+d}\gamma}$

1.3 Exclusive Leptonic and Semi-leptonic B-Decays

$|V_{cb}|$ from $B \to D(D^*)\ell\nu$

[Kowalewski@BEAUTY2011]

- Decay rate $d\Gamma \propto |F(q^2)|^2 \cdot |V_{cb}|^2$ requires $B \to D^{(*)}$ form factor
- $F(q^2_{\mathrm{max}}) = (1 + \text{corrections})$ from HQET and lattice/sum rules

$$|V_{cb}|_{\mathrm{excl}} = (38.9 \pm 0.9_{\mathrm{exp}} \pm 0.6_{\mathrm{th}}) \cdot 10^{-3}$$

$|V_{ub}|$ from $B \to \pi\ell\nu$

[Kowalewski@BEAUTY2011]

- $B \to \pi$ form factor normalization not fixed by HQET symmetries
- Extraction of $|V_{ub}|$ relies on lattice/sum rules and appropriate form-factor parameterisations (see below).

$$|V_{ub}|_{\mathrm{excl}} = (3.25 \pm 0.12_{\mathrm{exp}} \pm 0.28_{\mathrm{th}}) \cdot 10^{-3}$$

[BaBar+Belle+FNAL/MILC]

$|V_{ub}|$ from $B \to \tau\nu$

[Mannel@BEAUTY2011]

- Requires B-meson decay constant f_B (lattice).
- Experimental value for $B \to \tau\nu$ compared to $B \to \pi\ell\nu$ factor of 2 larger than theoretical prediction !?

Series Expansion for generic form factor $F(t = q^2)$:

[Boyd, Grinstein, Lebed, Savage, Caprini, Lellouch, Neubert, Becher, Hill, ...]

- Conformal Mapping:

$$z = z(t, t_0) = \frac{\sqrt{t_+ - t} - \sqrt{t_- - t_0}}{\sqrt{t_+ - t} + \sqrt{t_- - t_0}}\,, \qquad |z| \ll 1$$

with $t_\pm = (m_H \pm m_L)^2$ and $0 \leq t_0 < t_-$.

- (truncated) Series Expansion:

$$F(t) = \text{(pre-factor)(t)} \times \sum_{i=0}^{N} \alpha_i \cdot z^i$$

(pre-factor contains analytic structure from resonances outside the decay region)

- Coefficients α_i constrained by "Dispersive Bounds":

$$\sum_{i=0}^{N} |\alpha_i|^2 \leq 1$$

(from calculation of correlation functions with the corresponding decay currents)

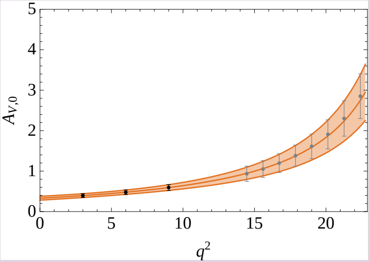
(Heavy-to-light) Form Factor Fits with Series Expansion

[Bharucha/TF/Wick 2010]

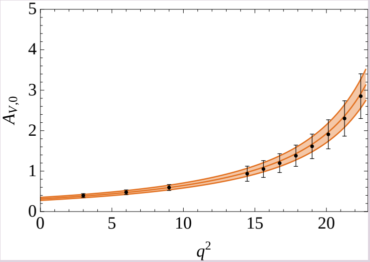
- FF at small momentum transfer $t = q^2$: from LCSR approach [QCDSF 0903.1664]
- FF at large momentum transfer $t = q^2$: Lattice QCD estimates [Ball/Zwicky 04]
- Interpolation: Truncated Series Expansion $(N = 1)$

Example: $B \to K$ transition form factors (vector current: $A_{V,0}(q^2) \equiv f_+(q^2)$)

LCSR only



LCSR + Lattice



1.4 Theory for $B \to K^{(*)}\mu^+\mu^-$ Decays

General amplitude for $B \to K^{(*)}\mu\mu$

- Hadronic amplitude A_{10}^{μ}, multiplying the lepton axial-vector current, entirely from local operator $\mathcal{O}_{10}$ in $H_{\rm eff}$ $\longrightarrow C_{10} \times$ (form factor)
- Hadronic amplitude A_9^{μ}, multiplying the lepton vector current,

$$
\begin{aligned}
A_9^{\mu} &= C_9 \, \langle \bar K^{(*)} | \bar s \gamma^\mu (1-\gamma_5) b | \bar B \rangle && \longrightarrow C_9 \times \text{(form factor)} \\
&+ C_7 \, \frac{2 i m_b \, q_\lambda}{q^2} \, \langle \bar K^{(*)} | \bar s \sigma^{\lambda\mu} (1+\gamma_5) b | \bar B \rangle && \longrightarrow C_7 \times \text{(form factor)} \\
&+ \langle \bar K^{(*)} | \, \mathcal{K}_H^{\mu}(q) \, | \bar B \rangle && \longrightarrow \begin{cases} q^2 \ll 4 m_c^2 & : \ \text{QCD factorization} \\ q^2 \gg 4 m_c^2 & : \ \text{OPE} \end{cases}
\end{aligned}
$$

  - $\mathcal{K}_H^{\mu}(q)$ from time-ordered product (non-local) between electromagnetic current and non-leptonic part of $H_{\rm eff}(b \to s)$.
  - leading order QCDF/OPE: sufficient to replace $C_9 \to C_9^{\rm eff}(q)$
  - sub-leading order in α_s and/or $1/m_b$: "Non-factorizable contributions": require further non-perturbative hadronic input !

Potential Issue: Duality violation from $B \to V(\to \mu^+\mu^-) K^*$ with $V = J/\psi, \psi', \ldots$

Duality Violation in $B \to K^{(*)}\mu^+\mu^-$ at high-q^2

[Beylich/Buchalla/TF 11] see also [Buchalla/Isidori 98, Grinstein/Pirjol 04, Khodjamirian et al. 10]

OPE for high-q^2 region: (above $c\bar{c}$ resonances)

- leading term in OPE from dim-3 operators, ($\to$ standard form factors)
  α_s corrections to $\langle \mathcal{K}_H^\mu \rangle_{\rm dim-3}$ known (and important) [...Seidel 04, Greub/Pilipp/Schüpbach 08]
- contributions from dim-4 operators suppressed $\alpha_s \frac{m_s}{m_b} \sim 0.5\%$
- contributions from dim-5 operators $\langle \bar{s} G^{\mu\nu} b \rangle$ estimated $< 1\%$
- dim-6 operators include weak annihilation effects, negligible at high-q^2 $\mathcal{O}(0.1\%)$

Duality-violating effects at high-q^2:

- Estimated on the basis of a model for an inifinite series of charm resonances, fitted to experimental R-ratio [Shifman 2000]
- Uncertainty on partially integrated decay rate ($q^2 \geq 15$ GeV^2) $\pm 2\%$

Duality violation for differential rate (point-by-point) remains model-dependent.

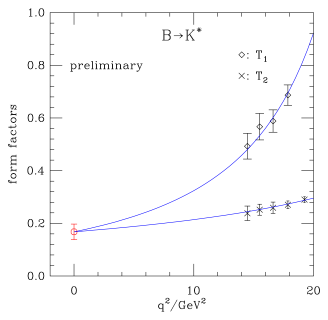
High-q^2 region of $B \to K^{(*)}\mu^+\mu^-$ under excellent theoretical control

$B \to K^{(*)}$ Form Factors from Lattice-QCD

[Liu et al, 1101.2726, 0911.2370, see also Wingate@BEAUTY2011]

- complementary to sum rules (large values of q^2)
- unquenchend gauge field configurations, moving NRQCD
  (2+1 flavours, $\mathcal{O}(a^2)$ tadpole-improved, staggered fermions, $m_\pi^{\rm simul.} \geq 300$ MeV, physical m_b)

Tensor Form Factors $T_{1,2}$ for $B \to K^*$ $(T_1(0) \equiv T_2(0))$



1.5 Charmless Non-Leptonic B-Decays

- Generic $B \to M_1 M_2$ amplitude can be written in terms of Topological Amplitudes:

  Colour-allowed and colour-suppressed "Tree" or "Penguin"

- In the SM, the relative weak phase is given by the CKM angle γ

- Different (partially controversial) approaches to estimate strong interaction effects

  QCD factorization / SCET, "perturbative QCD"

  - systematic calculation of perturbative corrections ?
  - size/reliability of $1/m_b$ power corrections ?
  - reliable calculation of colour-suppressed amplitudes ?
  - size of strong re-scattering phases ?

  [Beneke et al. 99; Bauer et al. 04; Keum et al. 00; ...]

- Phenomenological analyses make use of (approximate) flavour symmetries of QCD:
  - Isospin symmetry
  - $SU(3)$ flavour symmetry $\longleftarrow$ hadronic B_s-decays!

  [Fleischer/Zupan et al., Zupan@BEAUTY2011]

2. Theory II (Phenomenology and NP Models)

Present "Puzzles" in B-Observables:

- Tensions in $|V_{xb}|$:
  - small mismatch between $|V_{cb}|_{\rm incl.}$ and $|V_{cb}|_{\rm excl.}$
  - mismatch between $|V_{ub}|_{\rm incl.}$, $|V_{ub}|_{\rm excl.}$, $|V_{ub}|_{\tau\nu}$
- Tensions between $B \to \tau\nu$ and B_d-$\overline{B}_d$–mixing
- Tensions in $b \to s$ decays:
  - transverse polarization in $B \to \phi K^*$
  - A_{FB} in $B \to K^* \mu^+ \mu^-$
  - A_{CP} in $b \to s$ penguins
- Tensions in B_s-$\overline{B}_s$–mixing:
  - CP asymmetry from $B_s \to J/\psi\phi$
  - CP asymmetry in like-sign di-muon events from D0

Still room for NP $\to$ to be explored

2.1 Right-handed currents (effective theory approach)

[Buras/Gemmler/Isidori 10], see also [Crivellin 09]

- left-right symmetric flavour group,
- $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ global symmetry,
- New CKM'–Matrix in the right-handed sector,

Aim:

Resolve Tensions in
Different Determinations of $|V_{ub}|$.

Further:

- meson mixing
- $Z \to b\bar{b}$
- $B_{s,d} \to \mu\mu$
- $B \to X_s \nu\bar{\nu}$ (excl. & incl.)
- $K \to \pi\nu\bar{\nu}$
- $S_{\psi\phi}$ and $S_{\phi K}$

(RH currents in $b \to c\ell\nu$ can also be studied independently from moment analysis in $B \to X_c\ell\nu$ [Feger/Mannel et al. 10])

Implications for $|V_{ub}|$ Determinations (similar for other semi-leptonic decays)

$$|V_{ub}|_{B\to X_u\ell\nu} \longrightarrow \sqrt{|V_{ub}|^2 + \epsilon_R^2\,|\widetilde{V}_{ub}|^2}\,,$$

$$|V_{ub}|_{B\to\pi\ell\nu} \longrightarrow |V_{ub} + \epsilon_R\,\widetilde{V}_{ub}|\,,$$

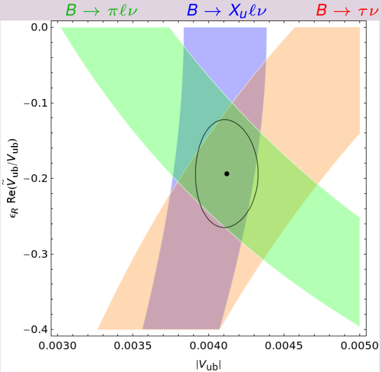
$$|V_{ub}|_{B\to\tau\nu} \longrightarrow |V_{ub} - \epsilon_R\,\widetilde{V}_{ub}|\,.$$

Determination of CKM and CKM' parameters:

$$\Rightarrow \qquad |V_{ub}| = (4.1 \pm 0.2)\cdot 10^{-3}\,,$$

$$\epsilon_R\,\mathrm{Re}\left(\frac{\widetilde{V}_{ub}}{V_{ub}}\right) = -0.19 \pm 0.07$$

- 2.7σ for RH current
- corresponds to $\Lambda_{\rm NP} \sim 3$ TeV



2.2 B-Meson Mixing

Mixing parameters:

- Neutral B_q-meson mixing ($q = d, s$) described by 2 complex 2×2 matrices:

$$\text{mass matrix:} \quad M_{ij}^q \,, \qquad \text{decay matrix:} \quad \Gamma_{ij}^q$$

- Observables:
  - mass splitting: $\Delta M_q \simeq 2|M_{12}^q|$, decay width difference: $\Delta\Gamma_q \simeq 2|\Gamma_{12}^q| \cos\phi_q$
  - flavour-specific CP asymmetry: $a_{\rm fs}^q = \frac{|\Gamma_{12}^q|}{|M_{12}^q|} \sin\phi_q$

  with mixing phase $\phi_q \equiv \arg(-M_{12}^q/\Gamma_{12}^q)$.

Time-dependent CP asymmetries:

- Consider decays dominated by $b \to c\bar{c}s$ transition:

$$A_{\rm CP}(t)^{B_q \to f} \simeq \pm S_f \, \sin(\Delta M_q t)$$

- For instance, $B_s \to J/\psi\phi$ in the SM:

$$S_{\psi\phi} = -\sin 2\beta_s \,, \qquad 2\beta_s = 2 \arg\left(\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right)$$

2.2 *B*-Meson Mixing in the SM

SM estimates (focus on B_s system) [Lenz/Nierste 11]

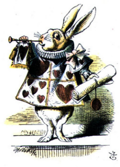
$$\Delta M_s^{\rm SM} = (17.3 \pm 2.6)\ {\rm ps}^{-1}\,, \qquad \Delta\Gamma_s^{\rm SM} = (0.087 \pm 0.021)\ {\rm ps}^{-1}\,,$$

and

$$\phi_s^{\rm SM} = 0.22^\circ \pm 0.06^\circ\,, \qquad S_{\psi\phi}^{\rm SM} = -0.036 \pm 0.002\,,$$

and

$$a_{\rm fs}^{s,{\rm SM}} = (1.9 \pm 0.3) \cdot 10^{-5}\,, \qquad a_{\rm fs}^{d,{\rm SM}} = -(4.1 \pm 0.6) \cdot 10^{-4}\,,$$



New Physics in B_s-$\overline{B}_s$–Mixing ?

- D0 measures

$$A_{\rm SL}^{\rm D0} = (0.506 \pm 0.043)\, a_{\rm fs}^{d} + (0.494 \pm 0.043)\, a_{\rm fs}^{s}$$
$$= -0.00957 \pm 0.00251 \pm 0.00146$$

  which significantly deviates from the SM estimate

$$A_{\rm SL}^{\rm SM} = -(2.0 \pm 0.3) \cdot 10^{-4}$$ [Lenz/Nierste 11]

- LHCb will be measuring [Lambert@BEAUTY2011]

$$2\,\Delta A_{\rm SL} = a_{\rm fs}^{s} - a_{\rm fs}^{d}$$

  for which the SM prediction reads $(4.3 \pm 0.7) \cdot 10^{-4}$.

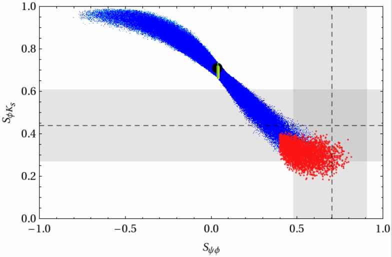
- Combined D0/CDF results on $S_{\psi\phi}$ yield

$$S_{\psi\phi} = 0.74^{+0.19}_{-0.23}$$

  which are significantly larger than the SM result.
- LHCb catches up quickly: $-2\beta_s^{J/\psi\phi} \in [-2.7, -0.5]$ @68% CL [Lambert@BEAUTY2011]

Example: $S_{\phi K_S}$ vs. $S_{\psi\phi}$ in a Model with 4th Quark Generation

Without constraint from ϵ'_K:



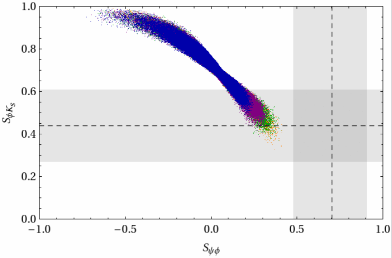
Colour Coding (*B*- and *K*-observables):

- (yellow) $S_{\psi\phi} = 0.04 \pm 0.01$ and $\mathrm{Br}(B_s \to \mu^+\mu^-) = (2 \pm 0.2) \cdot 10^{-9}$
- (red) $S_{\psi\phi} > 0.4$ and $\mathrm{Br}(B_s \to \mu^+\mu^-) > 6 \cdot 10^{-9}$
- (cyan) $\mathrm{Br}(K_L \to \pi^0\bar{\nu}\nu) > 2 \cdot 10^{-10}$ (blue) $\mathrm{Br}(K_L \to \pi^0\bar{\nu}\nu) < 2 \cdot 10^{-10}$

[Buras et al., arXiv:1002.2126 [hep-ph], arXiv:1004.4565 [hep-ph]]

Example: $S_{\phi K_S}$ vs. $S_{\psi\phi}$ in a Model with 4^{th} Quark Generation

Including constraint from ϵ'_K:



- Very large $S_{\psi\phi}$ not possible, if ϵ'_K constraint taken into account.

Colour Coding (hadronic matrix elements):

- $R_6 = 1.0$, $R_8 = 1.0$
- $R_6 = 1.5$, $R_8 = 0.8$
- $R_6 = 2.0$, $R_8 = 1.0$
- $R_6 = 1.5$, $R_8 = 0.5$

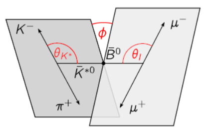
[Buras et al., arXiv:1002.2126 [hep-ph], arXiv:1004.4565 [hep-ph]]

2.3 Rare Semi-Leptonic B-Decays

- Based on rare $b \to s$ or $b \to d$ FCNCs $\Rightarrow$ NP Sensitivity
  - New sources of Flavour/CP-Violation beyond the SM

$$\mathcal{L} \stackrel{?}{=} \mathcal{L}_{\rm SM} + \sum_i \frac{C_i^d}{\Lambda_{\rm NP}^{4-d}} \mathcal{O}_i^{(d)}$$

- HQET/SCET symmetries reduce # of independent form factors.
- Variety of (theoretically controlable) Observables:
  - FB asymmetry in $B \to K^* \mu^+\mu^-$
  - Isospin asymmetry in $B \to K^* \mu^+\mu^-$
  - Angular asymmetries in $B \to K^*(K\pi)\mu^+\mu^-$



  - Decay rates for $B \to K^{(*)}\nu\bar{\nu}$
  - Decay rates for $B_q \to \mu^+\mu^-$
  - ...

[...Bobeth/Hiller et al., Beneke/TF/Seidel, Egede/Hurth/Krüger/Matias et al., Altmannshofer/Ball/Bharucha/Buras/Straub et al. ...]

[for a recent analysis, see also [Alok et al, 1103.5344]

$$\mathcal{H}_{\text{eff}}^{\Delta F=1} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum (C_i Q_i + C_i' Q_i')$$

which operators are relevant in which decay?

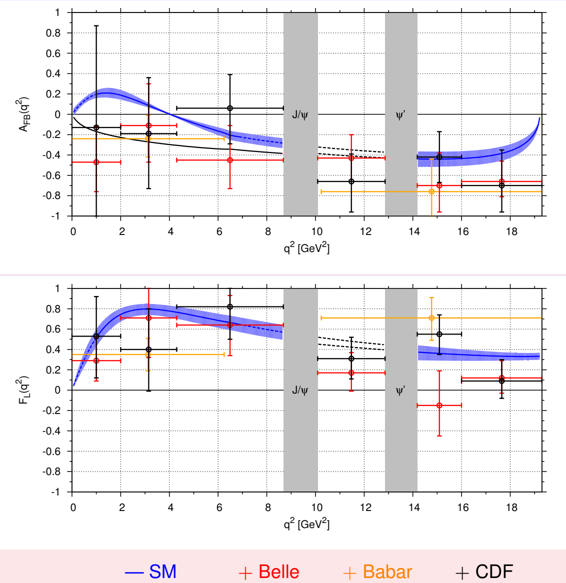
		$B \to X_s\gamma$	$B \to K^*\mu^+\mu^-$	$B_s \to \mu^+\mu^-$
mag. dipole operators	$Q_7^{(\prime)} \sim m_b(\bar{s}_{L,R}\sigma_{\mu\nu} b_{R,L}) F^{\mu\nu}$	X	X	
	$Q_8^{(\prime)} \sim m_b(\bar{s}_{L,R}\sigma_{\mu\nu} T^a b_{R,L}) G^{\mu\nu\, a}$	X	X	
semileptonic operators	$Q_9^{(\prime)} \sim (\bar{s}b)_{V\mp A}(\bar{\ell}\ell)_V$		X	
	$Q_{10}^{(\prime)} \sim (\bar{s}b)_{V\mp A}(\bar{\ell}\ell)_A$		X	X
scalar operators	$Q_S^{(\prime)} \sim m_b(\bar{s}b)_{S\pm P}(\bar{\ell}\ell)_S$			X
	$Q_P^{(\prime)} \sim m_b(\bar{s}b)_{S\pm P}(\bar{\ell}\ell)_P$			X

David Straub   Beauty 2011, Amsterdam

[Straub@BEAUTY2011]

Example: FB-Asymmetry and Longitudinal Fraction in $B \to K^* \mu^+ \mu^-$

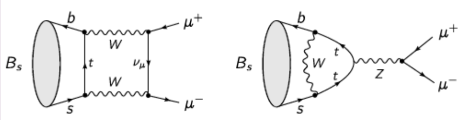
[Bobeth/Hiller/van Dyk 10]



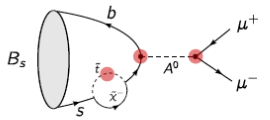
Phenomenology for $B_q \to \mu^+\mu^-$

- Hadronic uncertainty from decay constants f_{B_q} only.
- Helicity suppression in the SM:

$$\mathcal{B}(B_s \to \mu^+\mu^-)_{\rm SM} \sim 3 \cdot 10^{-9}\,, \qquad \mathcal{B}(B_d \to \mu^+\mu^-)_{\rm SM} \sim 0.1 \cdot 10^{-9}$$

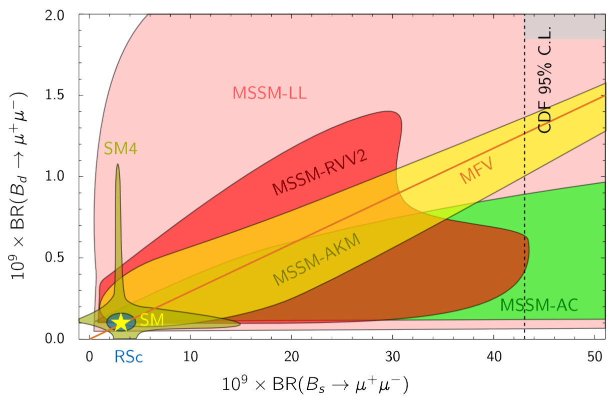


- Sizeable NP contributions possible, in particular for large $\tan\beta$:
  $\Rightarrow \mathcal{B}(B_s \to \mu^+\mu^-)_{\rm exp} < 10^{-8}$ would already rule out a number of NP models
- Correlations between $B_s \to \mu^+\mu^-$ and $B_d \to \mu^+\mu^-$
  as a test of Minimal Flavour Violation hypothesis (see below).



Correlation $B_s \to \mu\mu$ vs. $B_d \to \mu\mu$

- Minimal Flavour Violation (MFV): $\frac{\mathcal{B}(B_s \to \mu^+\mu^-)}{\mathcal{B}(B_d \to \mu^+\mu^-)} \simeq \frac{|V_{ts}|^2}{|V_{td}|^2}$
- 4th Generation Model [Buras et al. 10]
- SUSY Flavour Scenarios [Altmannshofer et al. 10]



[Straub@BEAUTY2011]

Outlook: Challenges for the LHC

LHCb is already performing extremely well . . . (ATLAS and CMS to follow)

The next year will be very exciting . . . [Uwer@BEAUTY2011]

Theory is trying to catch up . . .

- Control on factorization and perturbative uncertainties.
- Hadronic parameters (combining lattice/LCSR/exp. data).
- $SU(3)$ amplitude relations, including B_s decay modes.
- Identification of NP-sensitive observables.
- Constraints on parameter space of concrete NP models.
- Correlations between NP observables.

Challenge: Interpretation of combined data on flavour and high-$p_\perp$ observables !

Backup Slides

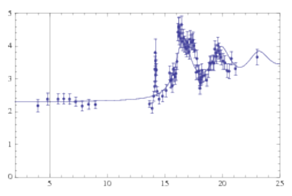
Modelling duality violation from charm-loop in $B \to K^{(*)}\mu^+\mu^-$

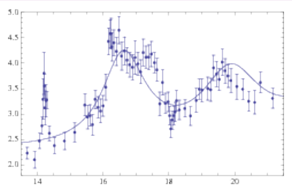
- Assume trajectory of charmonium resonances: $M_n^2 = n\lambda^2 + M_0^2$.
  (narrow resonances to be considered separately)

$\to$ Ansatz for R-ratio in the $c\bar{c}$-region:

$$R = R_{\text{light}} - \frac{4}{3}\,\frac{1}{(1-b/\pi)\,\pi}\,\mathrm{Im}\,\psi(3+z)\,, \qquad z = \left(-\frac{q^2 - 4m_c^2 + i\epsilon}{\lambda^2}\right)^{1-b/\pi}$$

- (crude) Fit to BES data :
  - $R_{\text{light}} = 2.31,$ from below charm threshold.
  - $m_c = 1.33$ GeV.
  - $\lambda^2 = 3.08\ \text{GeV}^2,$ from average distance of (broad) resonances.
  - $b = 0.082,$ from average width of (broad) resonances.





- Use same parameters to describe charm-contribution to $\langle \mathcal{K}_H^\mu \rangle$
  (assuming pessimistic scenario where all resonances contribute coherently)

[Beylich/Buchalla/TF, arXiv:1101.5118]