Discussion: $B \to K^{(*)}\ell^+\ell^-$ SM predictions

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Disclaimer

- These are some plots and comments to aid the discussion, not a seminar
  - References missing
  - Numerics are preliminary
  - All numbers (including mistakes!) obtained by me, comments about other people's work might be inaccurate
  - Slides do not make much sense by themselves (please contact me if you have questions, david.straub@tum.de)
- Thanks to Aoife Bharucha for providing preliminary LCSR results

Outline

1. High q^2 = low recoil

2. Low q^2 = large recoil

High q^2: ingredients

1. Effective Wilson coefficients
2. Form factors
3. Violation of quark-hadron duality (resonances . . .)

Effective Wilson coefficients

- perturbative uncertainties are small
- $C_{7,9}^{\text{eff}}$: important to include two-loop virtual corrections!
  [Asatryan et al., Seidel, Beneke/Feldmann/Seidel, Greub/Pilipp/Schupbach, . . .]
  - Lead to a $O(10\%)$ **suppression** of the BRs
  - Attention – different sign convention of [Seidel] vs. [Asatryan et al.] !
  - **Not** included in [Bouchard et al. 1306.0434] !
  - Included in [Bobeth et al., Beaujean et al., Altmannshofer et al., Horgan et al.]
  - Apparently **not** included in today's LHCb paper . . .

Form factors

- We finally have lattice FFs for $B \to K$, $B \to K^*$ and $B_s \to \phi$
- An independent confirmation by other lattice groups would be useful
- But old-school LCSR extrapolations are clearly deprecated, they depend a lot on the parametrization chosen
- Combining LCSR & lattice can instead be very useful, e.g. to fix/cross-check the normalization

Quark-hadron duality

This will be discussed in the resonances session, but to summarize Beylich/Buchalla/Feldmann [Beylich et al. 1101.5118] :

- The precise form of the “oscillation” depends on your model
- The q^2-integrated obs. *do not*, because an OPE exists
- Remaining uncertainty in the integrated rate estimated at $\pm 2\%$: negligible compared to FF uncertainty

Suggested treatment when looking for NP:

- Use large bin $[15\,\text{GeV}^2, q^2_{\text{max}}]$ and use OPE

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Suggested treatment when looking for NP:

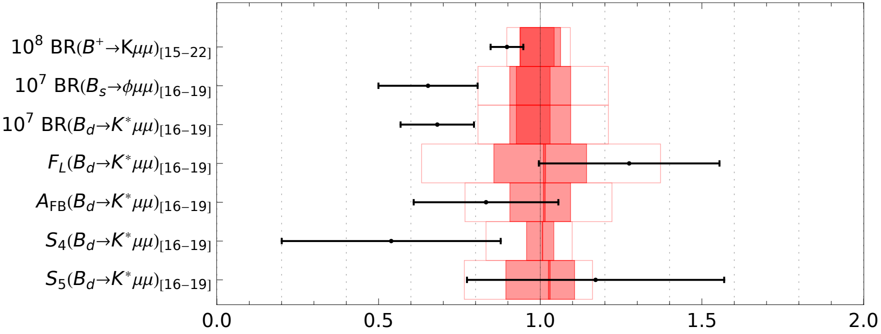
- Use large bin $[15\,\text{GeV}^2, q^2_{\text{max}}]$ and use OPE
- Fitting the q^2 dependence can then serve to test your model of the resonances

Now: numerics

- Lattice $B \to K$ and $B \to K^*$ FFs including all (known) error correlations
- Including parametric uncertainties (CKM, $m_{b,c}$, ...)
- All errors added in quadrature
- Neglecting duality violation following Beylich et al.
- Using [16–19] bin for $B \to K^*\mu\mu$ because data on [15–19] not yet available
- [15–19] bin for $B \to K\mu\mu$ available since Moriond
- Will only show LHCb experimental data (sorry)

NB, the following plots are inspired by a similar plot by Mitesh Patel at Moriond and a subsequent one by Wolfgang Altmannshofer

Numerics at high q^2: lattice FFs



- Normalized to SM central value; light boxes: SM $\pm 1\sigma$; dark boxes: parametric uncertainties only; empty boxes: “neglecting” parameter correlations; error bars: LHCb data

High q^2: summary

- Use lattice FFs
- Don't forget NNLO virtual corrections
- Use large bin $[15\,\text{GeV}^2, q^2_{\text{max}}]$ & OPE
- Combined fit to low & high q^2 form factors can serve as consitency check
- BR uncertainties start to be dominated by CKM
- $\text{BR}(B \to K\mu\mu)_{[15,22]}$ is consistent with the SM!

Outline

1. High q^2 = low recoil

2. Low q^2 = large recoil

Low q^2: ingredients

1. Effective Wilson coefficients (see high q^2)
2. Form factors
3. QCDF corrections in the $m_b \to \infty$ limit
4. Non-factorizable power corrections

Form factors

Soft vs. full

- 7 full FFs reduce to 2 soft FFs $\xi_{\perp,\|}$ in the heavy quark, large energy limit
- Difference between soft FFs & full FFs = factorizable power corrections

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LCSR form factors: 2 approaches

- Ball-Zwicky: requires K^* meson LCDA
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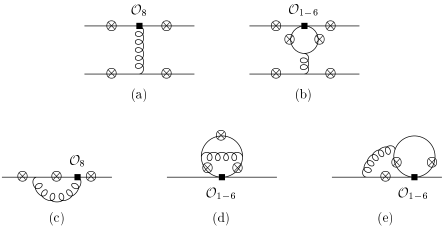
Parametrization & correlations

- Fitting the 7 form factors to (2 or 3-parameter) parametrizations, fit parameters typically highly correlated
- Including these correlations is crucial in observables involving ratios of FFs

QCD factorization

- Factorizable corrections: expressing the 7 full FFs in terms of the soft FFs. Not to be included when using full FFs
- Non-factorizable corrections: weak annihilation, spectator scattering, and form factor correction. NLO:



- QCDF breaks down at $q^2 \sim 6\ \mathrm{GeV}^2$ and cannot be trusted beyond (to be discussed)

Power corrections

- "factorizable PC": difference between soft & full FFs
- Non-factorizable PC: some partial results using LCSR [Lyon & Zwicky, Khodjamirian et al.]

Estimating unknown power corrections

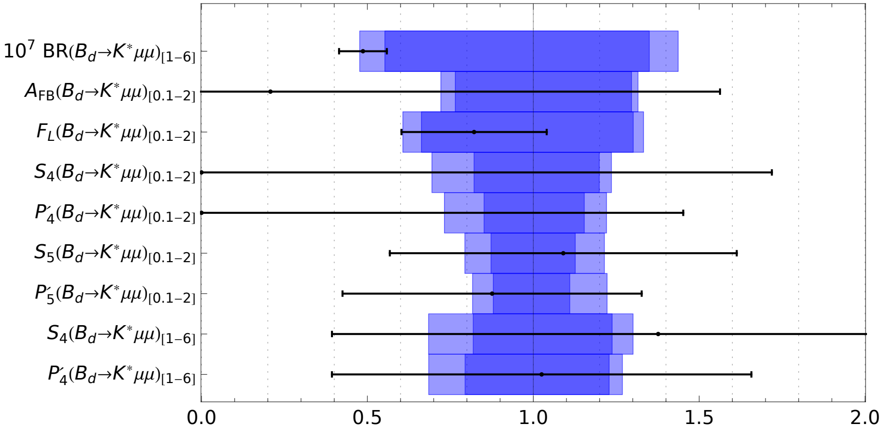
Possibilities:

1. Multiplying each spin amplitude by a fudge factor $f = (1 \pm \delta_{\text{pc}})$, e.g. $\delta_{\text{pc}} = 0.1$
   - Problematic for observables that cross 0 (A_{FB}, S_4, S_5) – emphasized by Sebastian Jäger at LHCb Implications Workshop 2013
2. Additive correction to spin amplitudes
   - In the following: multiply C_9^{SM} by $f = (1 \pm \delta_{\text{pc}})$, with δ_{pc} different for each spin amplitude
   - Other approaches? Multiply C_7? Helicity hierarchies of power corrections? (Camalich & Jäger)

Now: numerics

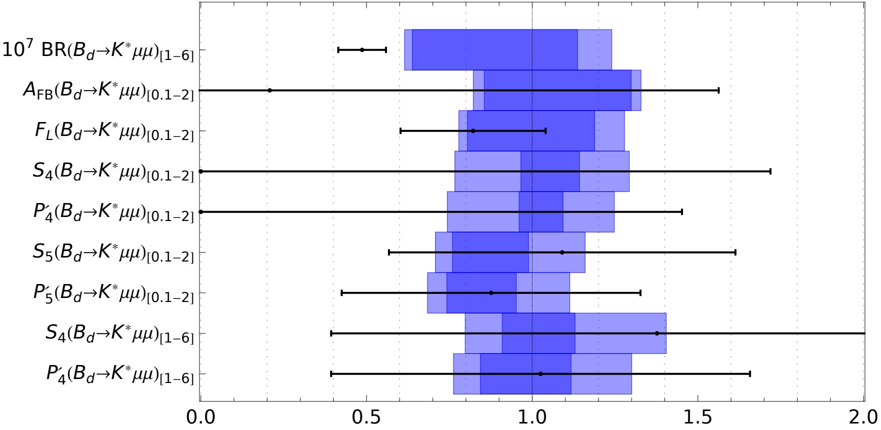
- Unknown non-factorizable corrections accounted for by $C_9^{\text{SM}}(1 \pm \delta_{\text{pc}})$ with $\delta_{\text{pc}} = 20\%$ different for each spin amplitude
- All errors added in quadrature
- Only LHCb data shown

Ball-Zwicky full FFs w/ correlations

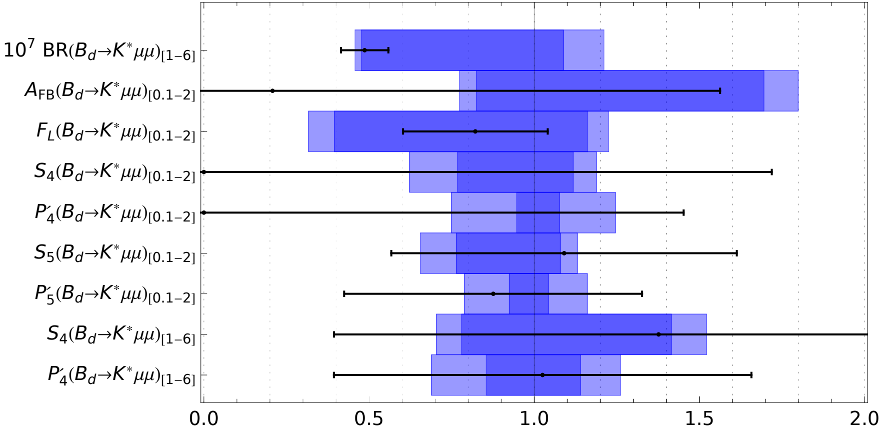


- Dark: $\delta_{\text{pc}} = 0$, light: $\delta_{\text{pc}} = 0.2$. Following plots normalized to these central values

Combined fit to Ball-Zwicky & lattice FFs



KMPW soft FFs (DMV-like)



- Perfectly consistent; $P'_{4,5}$ sensitive to PCs (fact. & non-fact.)

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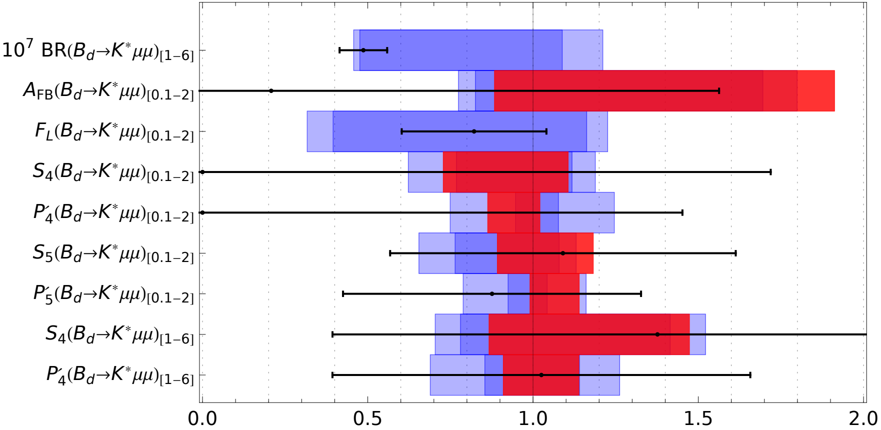
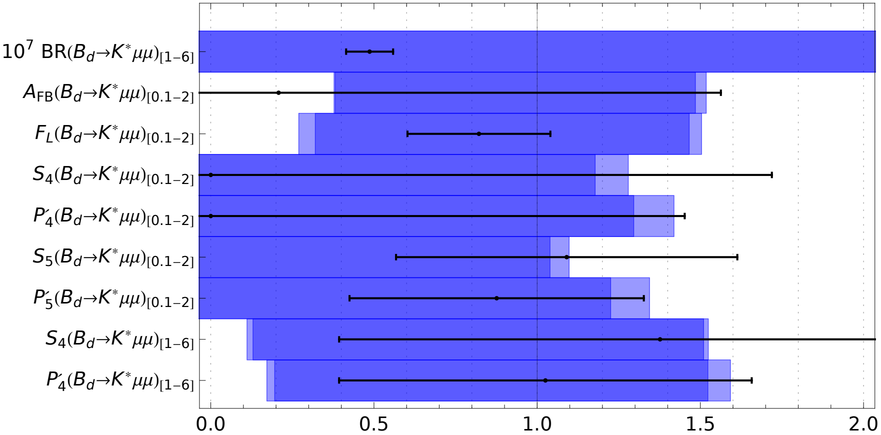


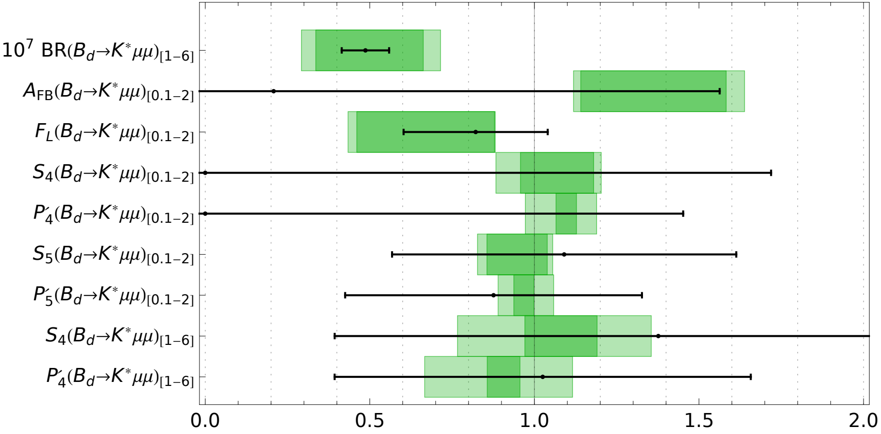
- Perfectly consistent; $P'_{4,5}$ sensitive to PCs (fact. & non-fact.)
- Comparing to numerics of DMV

KMPW full FFs, no correlations



- Huge (unphysical) uncertainties if fit correlations/FF constraints not taken into account

Camalich/Jäger soft FFs with and without $a + bq^2$



- Low BR due to normalization of $\xi_\perp(0)$ from $B \to K^*\gamma$ exp.

Low q^2: summary

- Main issues: form factors & estimate of unknown PCs
- Factorizable PCs taken into account when full FFs are used
- Correlation between FF fit parameters are crucial when using full FFs