LCSR results for B_s semileptonic decays

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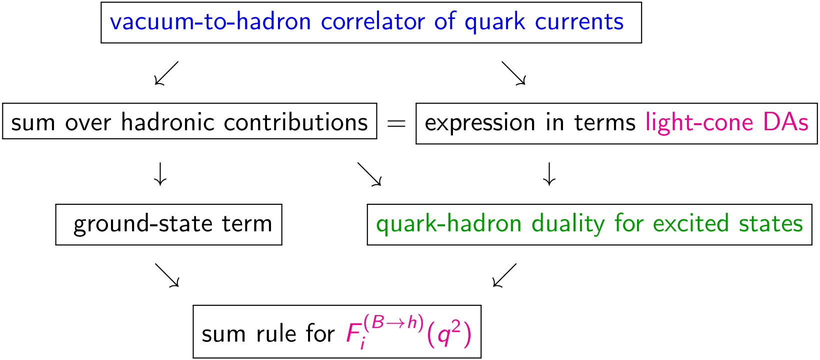
QCD Light-Cone Sum Rules

- QCD light-cone sum rule for a $F^{B\to h}(q^2)$ form factor, a general scheme:



- two different versions of LCSRs:
  - ∗ with light-meson DAs, $h = \pi, K, \rho, \omega, \phi, ...,$ m_b finite,
  - ∗ with $B_{(s)}$- meson DAs, defined in HQET
- both types of LCSRs valid at $q^2 \ll (m_B - m_h)^2$ (large recoil of h)

LCSRs for $B_s \to h$ form factors

- $O(m_s)$ effects taken into account
  (e.g. odd Gegenbauer moments in DAs or explicitly in the perturbative part)

- schematic expressions of the sum rules:
  - * with light meson DAs, $h = K, K^*, \phi$ — M^2-Borel parameter

$$F^{B_s \to h}(q^2) = \frac{e^{m_{B_s}^2/M^2}}{f_{B_s}} \int\limits_{(m_b+m_s)^2}^{s_0^{B_s}} ds\, e^{-s/M^2} \rho^{(h-DA)}(s, q^2, m_b)$$

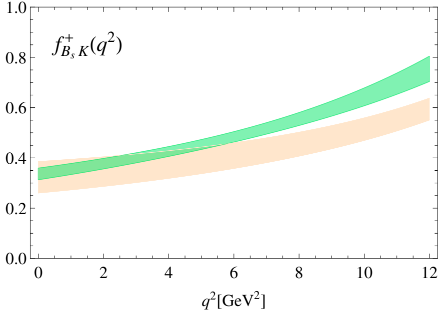
  - * with B_s-meson DAs,

$$F^{B_s \to h}(q^2) = \frac{e^{m_h^2/M^2}}{f_h} \int\limits_{m_s^2}^{s_0^h} ds\, e^{-s/M^2} \rho^{(B_s-DA)}(s, q^2, m_s)$$

- in what follows:
  - * $B_s \to K$ form factors used in $B_s \to K\mu\nu_\mu$;
  - * $B_s \to \phi\ell^+\ell^-$, the nonlocal effects ("charm loop")

$B_s \to K$ form factors from LCSR

- LCSR with kaon DAs, [AK, A.Rusov,1703.04765]



green -LCSR,
yellow - HPQCD extrapolation,
[HPQCD, 1406.2279, [hep-lat]]

∗ the integrated form factor squared:

$$\Delta\zeta_{B_sK}\,[0,q_0^2] \equiv \frac{G_F^2}{24\pi^3}\int\limits_0^{q_0^2} dq^2 p^3_{B_sK}|f^+_{B_sK}(q^2)|^2 = \frac{1}{|V_{ub}|^2\tau_{B_s}}\int\limits_0^{q_0^2} dq^2\,\frac{dB(\bar{B}_s\to K^+\ell\bar{\nu}_\ell)}{dq^2}\,,$$

∗ $\Delta\zeta_{B_sK}\,[0, 7.0\text{GeV}^2]$ was used by LHCb (PRL 126, 081804 (2021) to determine $|V_{ub}|/|V_{cb}|$ from the first measurement of $B_s \to K\mu\nu$

$B_s \to K$ form factor from LCSR

- A closer look at the K-DA sum rule:

$$F^{B_s\to K}(q^2) = \frac{e^{m_{B_s}^2/M^2}}{f_{B_s}} \int\limits_{(m_b+m_s)^2}^{s_0^{B_s}} ds\, e^{-s/M^2} \rho^{(K-DA)}(s, q^2, m_b, m_s)$$

  * the twist expansion in kaon DAs up to twist 6, the leading tw2,tw3 perturbative kernels to $O(\alpha_s)$
    the same level of accuracy as in LCSRs for $B \to \pi$ form factors
  * we use 2-point QCD sum rule result $f_{B_s} = 222^{+35}_{-21}$ MeV,
    cf FLAG $N_f = 4$ average $f_{B_s} = 230.3 \pm 1.3$ MeV
  * quark-hadron duality: B_s mass fixing from LCSR, B^*K threshold
  * switch to charm: e.g., LCSR: $f^+_{D\to K}(0) = 0.75^{+0.11}_{-0.08}$ [AK, C. Klein, T.Mannel, N.Offen, 0907.2842] cf FLAG average $f^+_{D\to K}(0) = 0.765 \pm 0.031$
  * counting uncertainties and correlations with Bayesian analysis
    for $B \to \pi$ pion-DA LCSR [I.S. Imsong, AK, T.Mannel and D.van Dyk, 1409.7816].

- not done yet: $B_s \to K$ form factor from B_s-DA LCSR
  recent estimate of the inverse moment of B_s DA [AK, R. Mandal,T. Mannel, 2008.03935].

$B_s \to \phi$ form factors

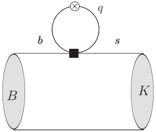
- LCSR with ϕ-meson DAs [A.Bharucha, D.M.Straub, R.Zwicky, [1503.05534].
  - ∗ up to twist 5 accuracy, NLO $O(\alpha_s)$ for tw2, tw3
  - ∗ impact of EOM
  - ∗ z-expansion
- not yet done: to convert to LCSR for the $D_s \to \phi$ form factors
- LCSR with B_s-meson DAs [N. Gubernari, D. van Dyk and J. Virto, 2011.09813]
  - ∗ up to twist 5 accuracy
  - ∗ including full three-particle B_s DAs
  - ∗ z-expansion
  - ∗ $O(\alpha_s)$ not included calculated for $B \to \pi$ LCSRs in [Y,-M. Wang, Y.-L. Shen (2015)]
  - ∗ still large uncertainties of the input parameters of $B_{(s)}$ DA

Local $B_s \to \phi$ form factors	This work	Ref. [36]
$V(q^2=0)$	0.387 ± 0.111	0.387 ± 0.033
$A_0(q^2=0)$	0.372 ± 0.070	0.389 ± 0.045
$A_1(q^2=0)$	0.304 ± 0.080	0.296 ± 0.027
$T_1(q^2=0)$	0.339 ± 0.093	0.309 ± 0.027
$T_{23}(q^2=0)$	0.651 ± 0.115	0.676 ± 0.071

$B_{(s)} \to h\ell^+\ell^-$,Nonlocal effects

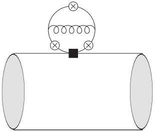
- Factorizable contributions: perturbative part $\times$ $B_s \to h$ form factor

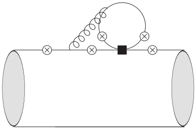
  - $*$ LO loop



  - $*$ NLO corrections

$\otimes$ -virtual photon

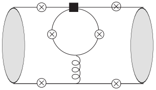


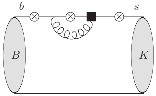


[H.M.Asatrian, C.Greub, J.Virto, 1912.09099].

- Nonfactorizable contributions

  - $*$ hard spectator scattering

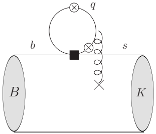


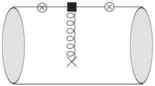


QCD factorization

[M.Beneke, T.Feldmann, D.Seidel, hep-ph/0412400].

  - $*$ soft (low virtuality) gluons





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B-DA LCSR

[AK., T.Mannel, A.A.Pivovarov, Y.-M.Wang, 1006.4945]

- Calculate at spacelike q^2 and match to the hadronic dispersion relations
  (with J/ψ , $\psi(2S)$ and light-vector resonances)

$B_s \to \phi \ell^+ \ell^-$

- SM prediction based on [A. Bharucha, D. M. Straub and R. Zwicky, 1503.05534].
  - ∗ LCSR with ϕ-meson DAs: form factors, factorizable nonlocal effects
  - ∗ soft nonfactorizable effects linearly parameterized,

    using also LCSR results for $B_s \to \phi\gamma$ [P.Ball, G.W.Jones,R.Zwicky, hep/ph/0612081]
  - ∗ branching fraction, F_L and S_4 predicted at $1.1 < q^2 < 6.0$ GeV^2

    $B_s \to \phi$-channel has an advantage due to small width of ϕ

- New updated soft gluon emission calcalation with B-DA LCSR predicts a very small effect [N. Gubernari, D. van Dyk and J. Virto, 2011.09813]

- A task for future: all nonfactorizable effects (hard spectator scattering, soft gluons, annihilation) in the LCSR framework with ϕ meson DAs, matching to dispersion relation;

  $B_s \to \phi J/\psi$, $B_s \to \phi\psi(2S)$ decay parameters as an input

- Conclusion: LCSRs in two different versions will serve a useful tool for counting the nonlocal effects in the exclusive FCNC B decays