$B_s \to K$ form factors from QCD Light-Cone Sum Rules

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Introduction

- Exclusive semileptonic $B_s \to K \ell \nu_\ell$ decay provides an additional source for the extraction of the CKM matrix element $|V_{ub}|$
- FCNC rare semileptonic $B_s \to K \ell^+ \ell^-$ decays are an additional probe of New Physics

$\to$ One needs an accurate calculation of the corresponding $B_s \to K$ form factors

- We derive them using the Light-Cone Sum Rules method

The definition of the form factors

$$\langle K(p)|\bar{q}\gamma^\mu b|B_s(p+q)\rangle = f^+_{B_sK}(q^2)\left[2p^\mu + \left(1 - \frac{m^2_{B_s} - m^2_K}{q^2}\right)q^\mu\right] + f^0_{B_sK}(q^2)\,\frac{m^2_{B_s} - m^2_K}{q^2}\,q^\mu$$

$$\langle K(p)|\bar{q}\sigma^{\mu\nu}q_\nu b|B_s(p+q)\rangle = \frac{i f^T_{B_sK}(q^2)}{m_{B_s} + m_K}\left[2q^2p^\mu + \left(q^2 - (m^2_{B_s} - m^2_K)\right)q^\mu\right]$$

- Involved in the semileptonic $\bar{B}^0_s \to K^+\ell^-\bar{\nu}_\ell$ and $\bar{B}^0_s \to K^0\ell^+\ell^-$ decays
- Needed in non-leptonic B_s decays (within QCDF approach)

$q = u, d,$ Isospin symmetry is assumed:

$$f^{(+,0,T)}_{B^0_sK^+}(q^2) = f^{(+,0,T)}_{B^0_sK^0}(q^2)$$

Correlation function

- Starting object used for calculation of $B_s \to K$ form factors in LCSR — Correlation function

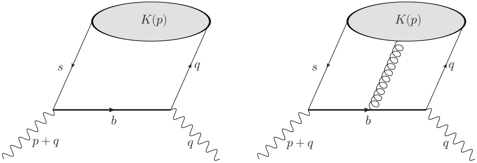
$$F^{\mu}_{B_s K}(p,q) = i\int d^4x\, e^{iqx}\langle K(p)|T\{\bar{q}(x)\Gamma^{\mu}b(x), m_b\bar{b}(0)i\gamma_5 s(0)\}|0\rangle$$

$$= \begin{cases} F_{B_s K}(q^2,(p+q)^2)p^{\mu} + \tilde{F}_{B_s K}(q^2,(p+q)^2)q^{\mu}, & \Gamma^{\mu} = \gamma^{\mu} \\ F^{T}_{B_s K}(q^2,(p+q)^2)\left[q^2 p^{\mu} - (q\cdot p)q^{\mu}\right], & \Gamma^{\mu} = -i\sigma^{\mu\nu}q_{\nu} \end{cases}$$

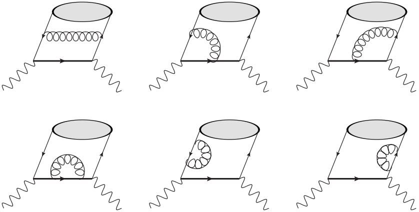
- Region of light-cone dominance ($x^2 \sim 0$)
  - $q^2 \ll m_b^2$
  - $(p+q)^2 \ll m_b^2$

Relevant OPE diagrams

- At leading order in α_s expansion



- Radiative corrections to the relevant hard-scattering kernels



The current accuracy of the OPE result

$$F^{(T)}_{B_s K}(q^2) \quad \Rightarrow \quad \mathrm{OPE} = \left(T_0^{(2)} + (\alpha_s/\pi) T_1^{(2)} + (\alpha_s/\pi)^2 T_2^{(2)} \right) \otimes \varphi_K^{(2)}$$

$$+ \frac{\mu_K}{m_b} \left(T_0^{(3)} + (\alpha_s/\pi) T_1^{(3)} \right) \otimes \varphi_K^{(3)} + T_0^{(4)} \otimes \varphi_K^{(4)} + \langle \bar{q} q \rangle \left(T_0^{(5)} \otimes \varphi_K^{(2)} + \frac{\mu_K}{m_b} T_0^{(6)} \otimes \varphi_K^{(3)} \right)$$

$$\mu_K = \frac{m_K^2}{m_s + m_q}, \quad \varphi_K^{(k)} = \text{AF + non-asympt. corrections}$$

- LO twist 2, 3, 4 $q\bar{q}$ and $\bar{q}qG$ terms
  [V.Belyaev, A.Khodjamirian, R.Rückl (1993); V.Braun, V.Belyaev, A.Khodjamirian, R.Rückl (1996)]
- NLO $O(\alpha_s)$ twist 2 (collinear factorization)
  [A.Khodjamirian, R.Rückl, S.Weinzierl, O. Yakovlev (1997); E.Bagan, P.Ball, V.Braun (1997)]
- NLO $O(\alpha_s)$ twist 3 (coll. factorization for asympt. DA)
  [P. Ball, R. Zwicky (2001); G.Duplancic, A.Khodjamirian, B.Melic, Th.Mannel, N.Offen (2007)]
- Part of NNLO $O(\alpha_s^2 \beta_0)$ twist 2 [A. Bharucha (2012)]
- LO twist 5 and twist 6 in factorization approximation [A.V. Rusov (2017)]

LCSR: a general scheme

- Transform the OPE result to the dispersion form (in $(p+q)^2$ variable):

$$F^{(T)(\mathrm{OPE})}_{B_s K}(q^2,(p+q)^2) = \frac{1}{\pi}\int\limits_{m_b^2}^{\infty} ds \frac{\mathrm{Im}F^{(T)(\mathrm{OPE})}_{B_s K}(q^2,s)}{s-(p+q)^2}$$

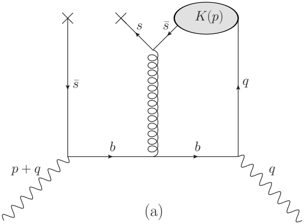
- Matching to the hadronic dispersion relation (isolating B_s-meson state)
- Applying the quark hadron duality
- Applying the Borel transform
- Finally

$$f^{+}_{B_s K}(q^2) = \frac{e^{m^2_{B_s}/M^2}}{2m^2_{B_s} f_{B_s}} \frac{1}{\pi}\int\limits_{m_b^2}^{s_0^{B_s}} ds\ \mathrm{Im}F^{(\mathrm{OPE})}_{B_s K}(q^2,s)e^{-s/M^2}$$

$$f^{T}_{B_s K}(q^2) = \frac{(m_{B_s}+m_K)e^{m^2_{B_s}/M^2}}{2m^2_{B_s} f_{B_s}} \frac{1}{\pi}\int\limits_{m_b^2}^{s_0^{B_s}} ds\ \mathrm{Im}F^{T(\mathrm{OPE})}_{B_s K}(q^2,s)e^{-s/M^2}$$

Factorizable twist-5 and twist-6 contributions

A.V. Rusov, 1705.01929 [hep-ph]



- An estimate of the twist-5 and twist-6 contributions is obtained in the factorization approximation

  [V.M. Braun, A. Khodjamirian, M. Maul (2000)], LCSR for $F_\pi(Q^2)$;

  [S.S. Agaev, V.M. Braun, N. Offen, F.A. Porkert (2011)], LCSR for $F_{\pi^0\gamma^*\gamma}(Q^2)$

Factorizable twist-5 and twist-6 contributions

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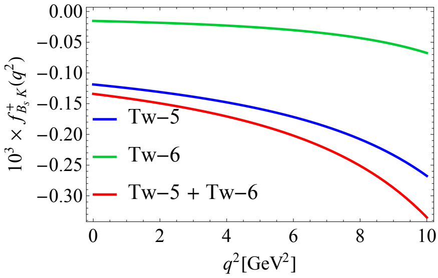

$f^+_{B_s K}(0)$	0.336
Tw2 LO	47.0%
Tw2 NLO	8.8%
Tw3 LO	47.1%
Tw3 NLO	−3.9%
Tw4 LO	1.0%
Tw5 LO-fact	−0.039%
Tw6 LO-fact	−0.005%

$$f^+_{B_s K}(0) = 0.336 \pm 0.023$$

[A. Khodjamirian, A.V. Rusov (2017)]

Higher twist contributions are strongly suppressed!

Results for the $B_s \to K$ form factors

A. Khodjamirian, A.V. Rusov, 1703.04765 [hep-ph]

LCSR results are fitted to the z-expansion (BCL parametrization)

$$f^{+,T}_{B_sK}(q^2) = \frac{f^{+,T}_{B_sK}(0)}{1 - q^2/m^2_{B^*}} \left\{ 1 + b^{+,T}_{1(B_sK)} \left[z(q^2) - z(0) + \frac{1}{2}\left(z(q^2)^2 - z(0)^2 \right) \right] \right\}$$

$$z(q^2) = \frac{\sqrt{(m_{B_s}+m_K)^2 - q^2} - \sqrt{(m_{B_s}+m_K)^2 - t_0}}{\sqrt{(m_{B_s}+m_K)^2 - q^2} + \sqrt{(m_{B_s}+m_K)^2 - t_0}}, \quad t_0 = (m_{B_s}+m_K)(\sqrt{m_{B_s}} - \sqrt{m_K})^2$$

$f^{+}_{B_sK}(0)$	$b^{+}_{1\,(B_sK)}$	Correlation
0.336 ± 0.023	-2.53 ± 1.17	0.79

$f^{T}_{B_sK}(0)$	$b^{T}_{1\,(B_sK)}$	Correlation
0.320 ± 0.019	-1.08 ± 1.53	0.74

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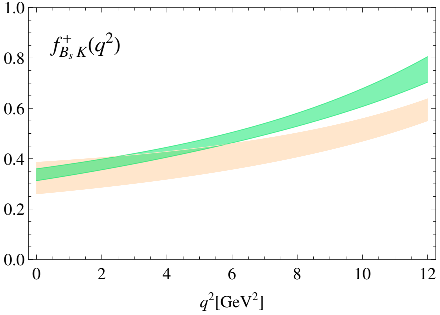

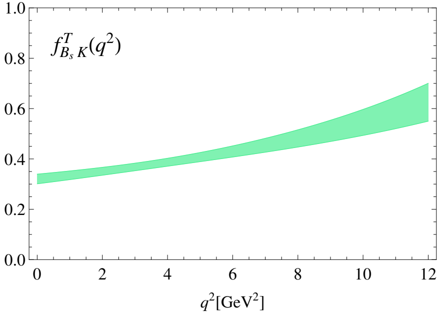

Lattice QCD results: C.M. Bouchard et al., hep-lat: 1406.2279

Applications

A. Khodjamirian, A.V. Rusov, 1703.04765 [hep-ph]

- The partially integrated $\bar{B}_s^0 \to K^+ \ell^- \bar{\nu}_\ell$ decay width

$$\Delta\zeta_{B_s K}\,[0, 12\,\mathrm{GeV}^2] \equiv \frac{1}{|V_{ub}|^2} \int\limits_0^{12\,\mathrm{GeV}^2} dq^2\, \frac{d\Gamma(\bar{B}_s \to K^+ \ell \bar{\nu}_\ell)}{dq^2} = 7.03^{+0.73}_{-0.69}\,\mathrm{ps}^{-1}$$

- The CP-averaged q^2-binned branching fraction of $\bar{B}_s^0 \to K^0 \ell^+ \ell^-$

$$\mathcal{B}_{B_s K}[q_1^2, q_2^2] \equiv \frac{1}{2} \frac{1}{q_2^2 - q_1^2} \int\limits_{q_1^2}^{q_2^2} dq^2 \left[\frac{dB(\bar{B}_s{}^0 \to K^0 \ell^+ \ell^-)}{dq^2} + \frac{dB(B_s^0 \to \bar{K}^0 \ell^+ \ell^-)}{dq^2} \right]$$

$$\mathcal{B}_{B_s K}[1.0\,\mathrm{GeV}^2,\, 6.0\,\mathrm{GeV}^2] = (4.38^{+0.62}_{-0.57} \pm 0.28) \times 10^{-8}\,\mathrm{GeV}^{-2}$$

- q^2-binned direct CP-asymmetry in $\bar{B}_s^0 \to K^0 \ell^+ \ell^-$ decays

$$\mathcal{A}_{B_s K}[1.0\,\mathrm{GeV}^2,\, 6.0\,\mathrm{GeV}^2] = -0.04^{+0.01}_{-0.03}$$

Conclusion

- $B_s \to K$ form factors at large recoil from LCSR are predicted
- The partially integrated $\bar{B}_s^0 \to K^+ \ell^- \bar{\nu}_\ell$ decay width is calculated (to be used for the $|V_{ub}|$ extraction)
- The CP-averaged q^2-binned branching fraction and q^2-binned direct CP-asymmetry in $\bar{B}_s^0 \to K^0 \ell^+ \ell^-$ decays are predicted (accounting nonlocal effects)
- Experimental data on $\bar{B}_s^0 \to K^0 \ell^+ \ell^-$ and $\bar{B}_s^0 \to K^+ \ell^- \bar{\nu}_\ell$ decays are anticipated