$B \to P, V$ Form Factors from Light-Cone Sum Rules

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An overview of the talk

- Introduction: Form Factors (FF) definition
- Motivation: The importance of FFs in physics and B anomalies
- Method: B light-cone Sum Rules (B-LCSR)
- Theoretical Results: New higher twist corrections to the B-LCSR
- Numerical Results: How big are these higher twist contributions?

Introduction: what are the Form Factors?

FFs are functions of q^2 that parametrize exclusive local hadronic elements. They are defined as follows:

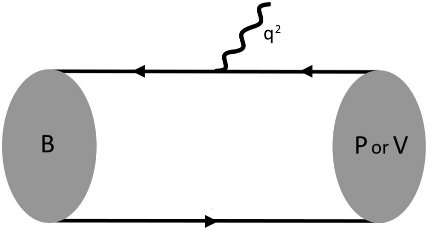
- for $B \to P$

$$\langle P(k)|\bar{q}_1\gamma_\mu b|\bar{B}(k+q)\rangle = 2k_\mu f^+_{BP}(q^2) + q_\mu[f^+_{BP}(q^2) + f^-_{BP}(q^2)]$$

- for $B \to V$

$$\langle V(k)|\bar{q}_1\gamma_\mu(1-\gamma_5)b|\bar{B}(k+q)\rangle = -i\varepsilon^*_\mu(M_B+M_V)A^{BV}_1(q^2) + i(2k+q)_\mu\frac{A^{BV}_2(q^2)}{M_B+M_V}$$
$$+ iq_\mu(\varepsilon^*\cdot q)\frac{2M_V\left[A^{BV}_3(q^2) - A^{BV}_0(q^2)\right]}{q^2} + \epsilon_{\mu\nu\rho\sigma}\varepsilon^{*\nu}q^\rho k^\sigma\frac{2V^{BV}(q^2)}{M_B+M_V}$$

[q^2 is the dilepton mass squared]

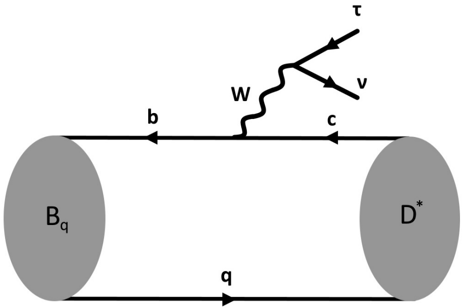


Motivations: why do we need $B \to P, V$ Form Factors?

In general $B \to P, V$ FFs are needed to

- predict decay amplitudes, such as $B \to \{P, V\}\bar{l}l$ or $B \to \{P, V\}l\nu_l$)

  [In this work we consider the final states: $P = \pi, K, D$ and $V = \rho, K^*, D^*$]
- extract $|V_{CKM}|$ element from branching ratios
- test the Standard Model and constrain new physics contributions

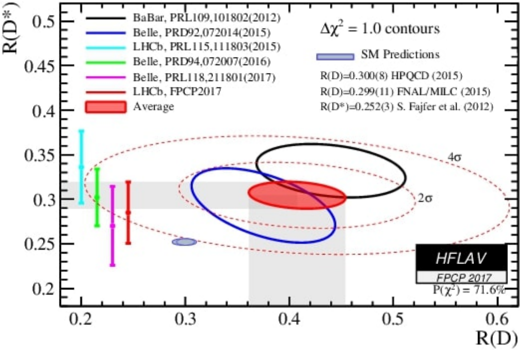


B anomalies: $R_{K^{(*)}}$ and $R_{D^{(*)}}$

LHCb, Belle and BaBar measurements exhibit a deviation with respect the SM prediction for the observables

$$R_{K^{(*)}} = \frac{BR(B \to K^{(*)}\mu^+\mu^-)}{BR(B \to K^{(*)}e^+e^-)} \qquad R_{D^{(*)}} = \frac{BR(B \to D^{(*)}\tau^+\nu)}{BR(B \to K^{(*)}\mu^+\nu)}$$

In both cases the combination of the results leads to a 4σ **deviation** from the SM prediction.



Method: The techniques to compute the FFs

QCD perturbation theory breaks down at low energy, hence **non perturbative techniques** are needed to compute local hadronic matrix elements, that is the form factors.

The most successful methods to compute $B \to P, V$ are FFs are Lattice QCD and light-cone sum rules.

Lattice QCD	**Light-cone sum rules**
spacetime discretization	quark-hadron duality
smaller error	bigger error
High q^2 (low recoil)	Low q^2 (large recoil)

Light-Cone Sum Rules in a nutshell

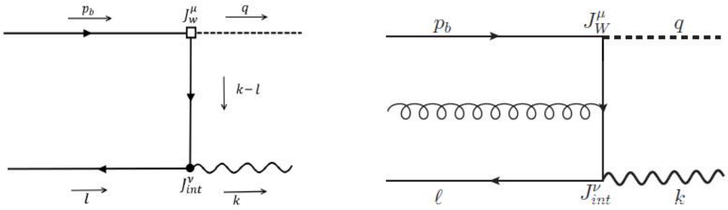
- LCSR are used to determine products of exclusive hadronic matrix elements from an artificial, less-exclusive, non-local hadronic matrix element $\Pi(k^2, q^2)$
- $\Pi(k^2, q^2)$ is then **expanded near the light-cone**

$$\Pi(k^2, q^2) = f_B m_B \int ds \sum_{n,t} \frac{J_{n,t}(s, q^2)}{[k^2 - s]^n} \phi_t(s)$$

- $J_{n,t}$ can be computed from a hard scattering kernel
- B-meson Light-Cone Distribution Amplitudes (LCDAs) ϕ_t are necessary non-perturbative input
  - general $B \to V$, $B \to P$ results available [Khodjamirian et al. '06 + '08]
  - new insights on LCDAs triggered our revisiting of these sum rule results [Braun/Ji/Manashov '17]

Theoretical results

- LCSRs togheter with lattice results and Heavy Quark expansions have been used in present analyses
- B-LCSRs have $1/m_b$ corrections (related to twist expansion)
- We present **new twist 4 corrections** to the $B \to P, V$ LCSRs, higher twists are expected to give corrections only of the order $O(1/m_b^2)$
- $O(\alpha_s)$ corrections are not considered



Numerical Results and Comparison

$B \to D^*$ FF	FKKM2008 2pt tw2+3 + 3pt	GKvD2018 2pt tw2+3 + 3pt*	GKvD2018 NEW Contrib. 2pt tw4
$A_0(q^2=0)$	0.78	0.79	-10%
$A_1(q^2=0)$	0.73	0.73	-12%
$A_2(q^2=0)$	0.66	0.65	-17%
$A_0(0)/A_1(0)$	1.07	1.09	+3%

[using the same input parameters, with q^2 the dilepton mass square]

ϕ_+, ϕ_- 2-particle L+NL twist contributions [Faller/Khodjamirian/Klein/Mannel '06]

$\mathbf{g}_+$ **new** 2-particle NNL twist contributions [Gubernari/Kokulu/van Dyk w.i.p.]

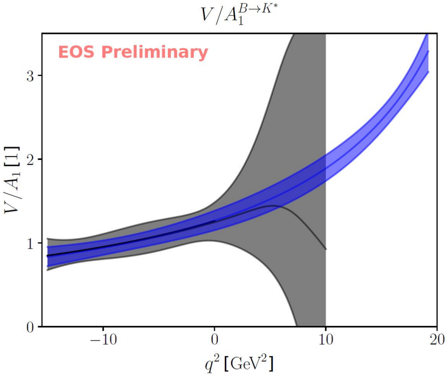
ϕ_3, ϕ_4 **new and self-consistent** 3-particle NL+NNL twist contr. [Gubernari/Kokulu/van Dyk w.i.p.]

Combining Lattice with LCSRs

- Uncertainties for the LCSRs are of similar size as in previous works
- To improve the knowledge of the FFs over the whole q^2 range, we fit LCSR and Lattice results to the BSZ2015 parametrization.

[Bharucha, Straub, Zwicky 2015]

- The fit to the BSZ2015 parametrization makes uncertainties smaller



Thank you for your attention!

Power corrections

- correlator is calculated with on-shell B meson, using its Light-Cone Distribution Amplitudes (LCDAs)
- B-meson LCDAs are defined for bi-local currents involving an HQET field h_v
- power corrections to this involve power of the covariant derivative iD^μ
- strings of the type $iD^{\mu_1}\, iD^{\mu_2} \ldots iD^{\mu_n}$ are incorporated in LCDAs of increasing (collinear) twist

Benefits of the Braun et al. basis

- ϕ_3, ϕ_4, ... are LCDAs of definite collinear twist 3, 4, ...
- LCDAs of twists ≥ 5 are expected to contribute *beyond* the next-to-leading $1/m_b$ corrections! [Braun/Ji/Manashov '17]
- inserting a gluon field adds at least one unit of twist
  - 2-particle LCDAs start at twist 2, and are included in our results (up to and including twist 4)
  - 3-particle LCDAs start at twist 3, and are included in our results (up to and including twist 4)
  - 4-particle LCDAs start at twist 4, and are *not included in our results*
  - 4-particle LCDAs have autonomous RG behaviour, *do not mix with 3-particle LCDAs*

[Braun/Ji/Manashov '17]