Semi-leptonic form factors for rare B decays
(Short distance contributions)

Edwin Lizarazo

for the RBC and UKQCD collaborations
University of Southampton

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The RBC-UKQCD collaboration:

BNL and RBRC:

Mattia Bruno, Tomomi Ishikawa, Taku Izubuchi, Chulwoo Jung, Christoph Lehner, Meifeng Lin, Hiroshi Ohki,

Shigemi Ohta (KEK), Amarjit Soni, Sergey Syritsyn

Columbia University:

Ziyuan Bai, Norman Christ, Luchang Jin, Christopher Kelly, Bob Mawhinney, Greg McGlynn, David Murphy, Jiqun Tu

University of Connecticut:

Tom Blum

York University (Toronto):

Renwick Hudspith

University of Edinburgh:

Peter Boyle, Guido Cossu, Luigi Del Debbio, Richard Kenway, Julia Kettle, Ava Khamseh, Antonin Portelli, Oliver Witzel,

Azusa Yamaguchi

University of Southampton:

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CERN:

Marina Marinkovic

KEK:

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Pekin University:

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RBC/UKQCD B physics program

- Decay constants f_B and f_{B_s} [PRD 91 (2015) 054502]
- $g_{B^* B\pi}$ coupling constant [PRD 91 (2015) 074510]
- $B^0 - \bar{B}^0$ mixing
- Semileptonics:

$$b \to u \quad : \quad \begin{cases} B \to \pi\ell\nu \\ B_s \to K^{(*)}\ell\nu \end{cases}$$

[PRD91(2015)074510]

$$b \to c \quad : \quad \begin{cases} B \to D^{(*)}\ell\nu \\ B_s \to D_s^{(*)}\ell\nu \end{cases}$$

O. Witzel Wed 10:20

$$b \to s \quad : \quad \begin{cases} B \to K^{(*)}\ell^+\ell^- \\ B_s \to \phi\ell^+\ell^- \end{cases}$$

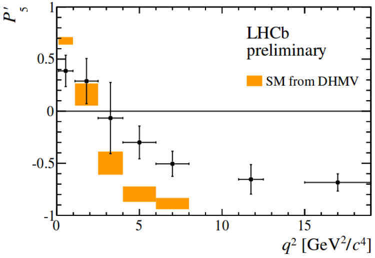
This talk

Phenomenological motivation

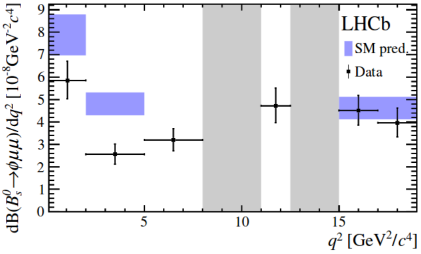
- $b \to s, d$ decays:

  Involve flavour changing neutral currents.

  Opportunity to discover and probe New Physics.



$B^0 \to K^{*0}\mu^+\mu^-$ [arXiv:1506.08777v1]



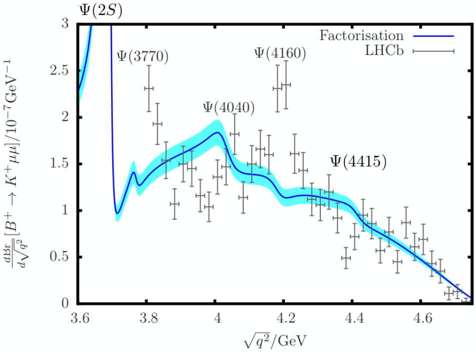
$B_s^0 \to \phi\mu^+\mu^-$ [LHCb-CONF-2015-002]

- Experiments cover the whole kinematical range $0 < q^2 < (m_{B_s} - m_\phi)^2$.
- Lattice QCD: Only one full LQCD study with vector final states.

[PRD 89 (2014) 094501]

Phenomenological motivation

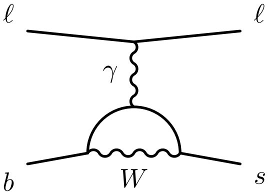
- Charm resonance effects under discussion [arXiv:1406.0566 [hep-ph]]

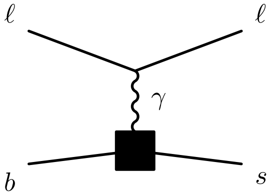


- Objective:

Differential branching fractions and angular distributions in full LQCD

Theoretical framework: Effective Hamiltonian





$$\mathcal{H}_{\text{eff}}^{b\to s} = -\frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} \sum_i^{20} C_i O_i$$

- Wilson coefficient's C_i known to NNLO
- Leading contributions to local interactions are given by:

$$O_7^{(\prime)} = \frac{m_b e}{16\pi^2} \bar{s}\sigma^{\mu\nu} P_{R(L)} b \; F_{\mu\nu}$$

$$O_9^{(\prime)} = \frac{e^2}{16\pi^2} \bar{s}\gamma^\mu P_{L(R)} b \; \bar{\ell}\gamma_\mu \ell$$

$$O_{10}^{(\prime)} = \frac{e^2}{16\pi^2} \bar{s}\gamma^\mu P_{L(R)} b \; \bar{\ell}\gamma_\mu \gamma^5 \ell$$

Theoretical framework: Form factors

$$\langle V(k,\varepsilon)|\bar{q}\gamma^\mu b|B_{(s)}(p)\rangle = f_V(q^2)\frac{2i\epsilon^{\mu\nu\rho\sigma}\varepsilon^*_\nu k_\rho p_\sigma}{M_{B_{(s)}}+M_V}$$

$$\begin{aligned}\langle V(k,\varepsilon)|\bar{q}\gamma^\mu\gamma_5 b|B_{(s)}(p)\rangle &= f_{A_0}(q^2)\frac{2M_V\varepsilon^*\cdot q}{q^2}q^\mu \\ &+ f_{A_1}(q^2)(M_{B_{(s)}}+M_V)\left[\varepsilon^{*\mu}-\frac{\varepsilon^*\cdot q}{q^2}q^\mu\right] \\ &- f_{A_2}(q^2)\frac{\varepsilon^*\cdot q}{M_{B_{(s)}}+M_V}\left[k^\mu+p^\mu-\frac{M^2_{B_{(s)}}-M^2_V}{q^2}q^\mu\right]\end{aligned}$$

$$q_\nu\langle V(k,\varepsilon)|\bar{q}\sigma^{\nu\mu}b|B_{(s)}(p)\rangle = f_{T_1}(q^2)2\epsilon^{\mu\rho\tau\sigma}\varepsilon^*_\rho k_\tau p_\sigma$$

$$\begin{aligned}q_\nu\langle V(k,\varepsilon)|\bar{q}\sigma^{\nu\mu}\gamma^5 b|B_{(s)}(p)\rangle &= f_{T_2}(q^2)i\left[\varepsilon^{*\mu}(M^2_{B_{(s)}}-M^2_V)-(\varepsilon^*\cdot q)(p+k)^\mu\right] \\ &+ f_{T_3}(q^2)i(\varepsilon^*\cdot q)\left[q^\mu-\frac{q^2}{M^2_{B_{(s)}}-M^2_V}(p+k)^\mu\right]\end{aligned}$$

Theoretical framework: Obtaining the f_V form factor for $B_s \to \phi \ell^+ \ell^-$

The form factor f_V can be obtained from

$$f_V(q^2) = \frac{iR^{\gamma^j \gamma^i}_{B_s \to \phi}(\vec{k})(m_{B_s} + m_\phi)}{2 m_{B_s} \epsilon^{0ijk} k_k} \quad \text{(no } i, j \text{ sum)}$$

where

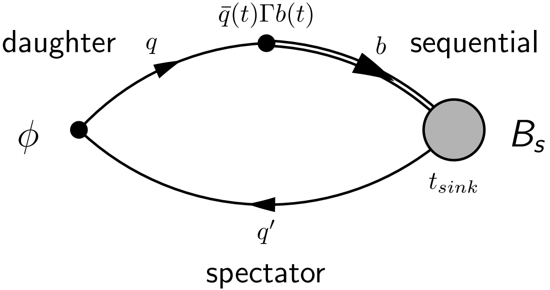
$$R^{\gamma^j \gamma^i}_{B_s \to \phi}(t, t_{\mathrm{sink}}, k) = \frac{C^{\gamma^j \gamma^i}_{B_s \to \phi}(t, t_{\mathrm{sink}}, k)}{\sqrt{\frac{1}{3} \sum_i C^{ii}_\phi(t, k) C_{B_s}(t_{\mathrm{sink}} - t)}} \sqrt{\frac{4 E_\phi M_{B_s} \sum_\lambda \varepsilon^j(k, \lambda) \varepsilon^{j*}(k, \lambda)}{e^{-E_\phi t} e^{-M_{B_s}(t_{\mathrm{sink}} - t)}}}$$

$$\xrightarrow{t, t_{\mathrm{sink}} \to \infty} \sum_\lambda \varepsilon^j(k, \lambda) \langle \phi(k, \lambda) | \bar{q} \gamma^i b | B_s(p) \rangle .$$

and

$$\sum_\lambda \epsilon^\mu(k, \lambda) \epsilon^{\nu *}(k, \lambda) = \frac{k^\mu k^\nu}{m_V^2} - g^{\mu\nu}$$

3-point function setup



- sequential: RHQ *b*-quark tuned following [PRD 86 (2012) 116003]

$$S = \sum_n \overline{\psi}_n \left(m_0 + \gamma_0 D_0 + \zeta \vec{\gamma} \cdot \vec{D} - \frac{a}{2}(D_0)^2 - \frac{a}{2}\zeta(\vec{D})^2 + \sum_{\mu,\nu} \frac{ia}{4} c_p \sigma_{\mu\nu} F_{\mu\nu} \right) \psi_n$$

- spectator and daughter: DWF light or strange quark

RBC/UKQCD 2+1 flavor DWF and Iwasaki gauge field ensembles

$24^3 \times 64$: $a^{-1} = 1.78$ GeV, 1 source per configuration

- $M_\pi = 338$ MeV, 1636 configurations (complete)
- $M_\pi = 434$ MeV, 1419 configurations (complete)

$32^3 \times 64$: $a^{-1} = 2.38$ GeV, 2 sources per configuration

- $M_\pi = 301$ MeV (3 point functions to be computed)
- $M_\pi = 362$ MeV, 889 configurations, 1 source (in progress)
- $M_\pi = 411$ MeV (3 point functions to be computed)

$48^3 \times 96$: $a^{-1} = 2.76$ GeV, 24 sources per configuration

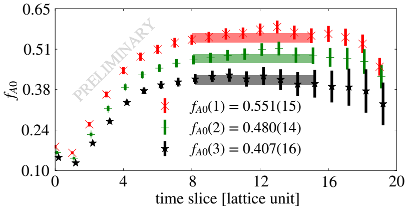
- $M_\pi \sim 250$ Mev, 50 configurations (only s-quarks)

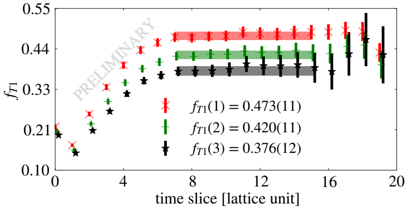
$48^3 \times 96$: $a^{-1} = 1.73$ GeV, $81 \to 162$ sources per configuration

- $M_\pi = 139$ MeV, 40 configurations (3pt functions to be computed)

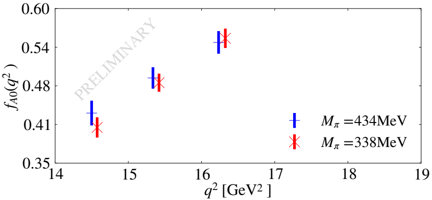
Preliminary results for $B_s \to \phi\ell^+\ell^-$ on 24^3

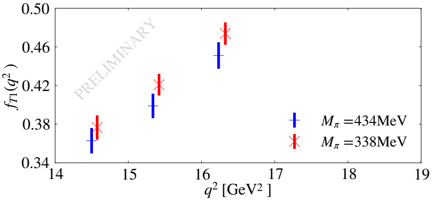
$M_\pi = 338$ MeV





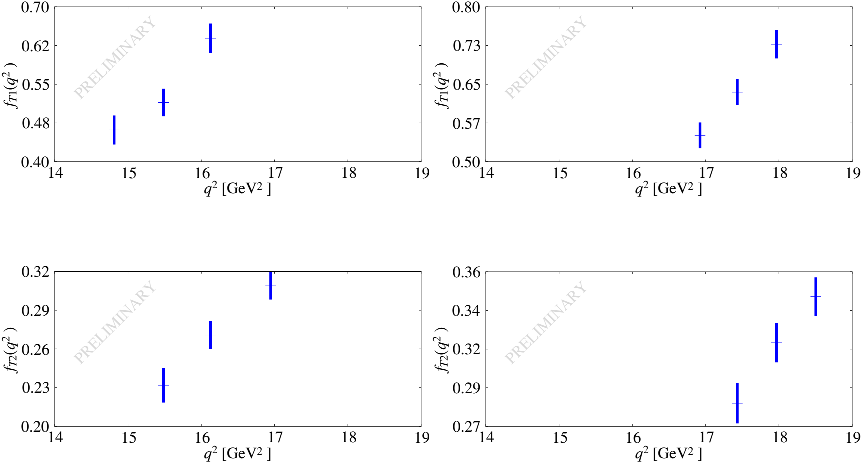
$M_\pi = 338$ MeV and $M_\pi = 434$ MeV





Preliminary results for $B_s \to \phi\ell^+\ell^-$ on 32^3 and 48^3

$M_\pi = 362$ MeV $\qquad$ $M_\pi \sim 250$ MeV



$\mathcal{O}(a)$ improved currents and the building blocks code

- Vector and Axial vector currents

$$V_\mu^1 = 2\bar{\psi}\overrightarrow{D}_\mu b \qquad V_\mu^2 = 2\bar{\psi}\overleftarrow{D}_\mu b$$

$$V_\mu^3 = 2\bar{\psi}\gamma_\mu\gamma^i\overrightarrow{D}_i b \qquad V_\mu^4 = 2\bar{\psi}\gamma_\mu\gamma^i\overleftarrow{D}_i b$$

- Tensor and Pseudotensor currents

  Extra terms have been classified based on discrete symmetries

- Building blocks code

  Compute all 144 matrix elements:

$$\underbrace{\langle V|\bar{\psi}\Gamma b|B_{(s)}\rangle}_{16} \qquad \underbrace{\langle V|\bar{\psi}\Gamma\overrightarrow{D} b|B_{(s)}\rangle}_{16\cdot 4} \qquad \underbrace{\langle V|\bar{\psi}\overleftarrow{D}\Gamma b|B_{(s)}\rangle}_{16\cdot 4}$$

  and perform linear combinations post-processing.

Renormalisation of lattice form factors

- Renormalisation of vector and axial currents is done following

[PRD 64 (2001) 014502]

$$\langle V|\psi\Gamma b|B_{(s)}\rangle_{\text{renormalised}} = \rho_\Gamma^{b\psi}\sqrt{Z_\Gamma^{bb}Z_\Gamma^{\psi\psi}}\langle V|\psi\Gamma b|B_{(s)}\rangle_{\text{bare}}$$

where:

$\rho_\Gamma^{b\psi}$ is close to 1 and is obtained using lattice perturbation theory

[RBC/UKQCD Physyhcal]

and the flavor conserving factors $Z_\Gamma^{\psi\psi}$, Z_Γ^{bb} with

$\Gamma = \gamma^\mu, \gamma^\mu\gamma^5$ are computed non perturbatively

- Tensor currents $\Gamma = \sigma^{\mu\nu}, \sigma^{\mu\nu}\gamma^5$ will be renormalised perturbatively

$$\langle V|\psi\Gamma b|B_{(s)}\rangle_{\text{renormalised}} = \rho^{b\psi}\langle V|\psi\Gamma b|B_{(s)}\rangle_{\text{bare}}$$

Next steps

- Obtain results for all ensembles (finer lattice spacing, physical pions).
- Include O(a) improvement.
- Renormalize form factors and do a global analysis.
- Phenomenological analysis.

Thank you!