Semileptonic form factors for $B_s \to D_s \ell\nu$ and $B_s \to K \ell\nu$ decays

Jonathan M. Flynn, Ryan C. Hill, Andreas Jüttner, Amarjit Soni, J. Tobias Tsang, and Oliver Witzel (RBC-UKQCD collaboration)

INTRODUCTION

Motivation

- LHC experiments collect sufficiently many B_s mesons
- Measurements at the LHC are complementary to those at B-factories
- Only spectator quark differs compared to $B \to \pi\ell\nu$ and $B \to D\ell\nu$
- Alternative determination of the CKM ratio V_{cb}/V_{ub}
- Independent test of lepton flavor universality; $R^{\tau/\mu}_{D_s}$ probably a good proxy for $R^{\tau/\mu}_{D}$
- Numerically more precise prediction of form factors
- Preparation to determine $B_{(s)} \to D^*_{(s)}\ell\nu$ form factors

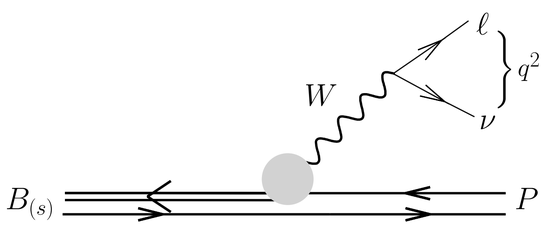
Numerical set-up

- Domain wall fermions (DWF) [1-3] for up, down, and strange quarks
- Heavy Möbius DWF [4] for charm-like quarks [5]
- Relativistic heavy quark (RHQ) action for bottom quarks [6,7]
- RBC-UKQCD's 2+1 flavor DWF+Iwasaki gauge field ensembles [8-11]

	L	a^{-1}(GeV)	am_l	am_s	M_π(MeV)	# configs.	#sources
C1	24	1.785	0.005	0.040	338	1636	1
C2	24	1.785	0.010	0.040	434	1419	1
M1	32	2.383	0.004	0.030	301	628	2
M2	32	2.383	0.006	0.030	362	889	2
M3	32	2.383	0.008	0.030	411	544	2
F1*	48	2.774	0.002144	0.02144	234	98	24

* Preliminary — study of ensemble properties/data generation ongoing

Kinematic set-up: $B_{(s)}$ meson rest frame



Definition of form factors f_+ and f_0

$$\langle P|V^\mu|B_{(s)}\rangle = f_+(q^2)\left(p^\mu_{B_{(s)}} + p^\mu_P - \frac{M^2_{B_{(s)}} - M^2_P}{q^2}q^\mu\right) + f_0(q^2)\frac{M^2_{B_{(s)}} - M^2_P}{q^2}q^\mu$$

for pseudoscalar final state $P = D_s$, K, D, π

z parametrization

Bourrely, Caprini, and Lellouch (BCL) [12]

$$f_+(q^2) = \frac{1}{1 - q^2/M^2_{B^*}}\sum_{k=0}^{K-1} b^{(k)}_+\left[z^k - \frac{k}{K}(-1)^{k-K}z^K\right]$$

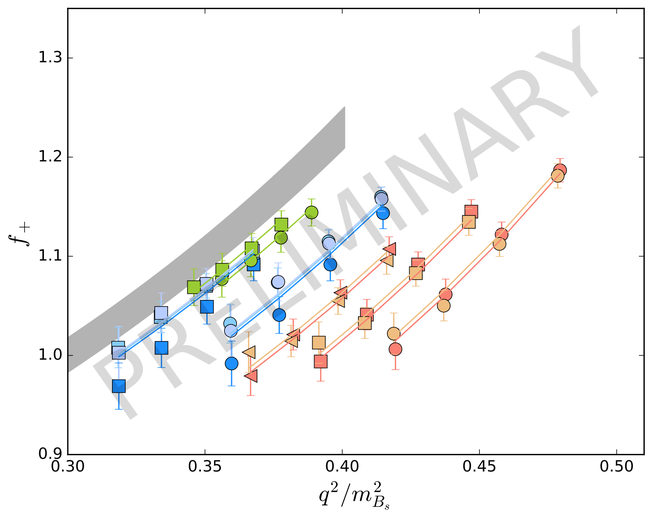
$$f_0(q^2) = \frac{1}{1 - q^2/M^2_{B^*(0^+)}}\sum_{k=0}^{K-1} b^{(k)}_0 z^k$$

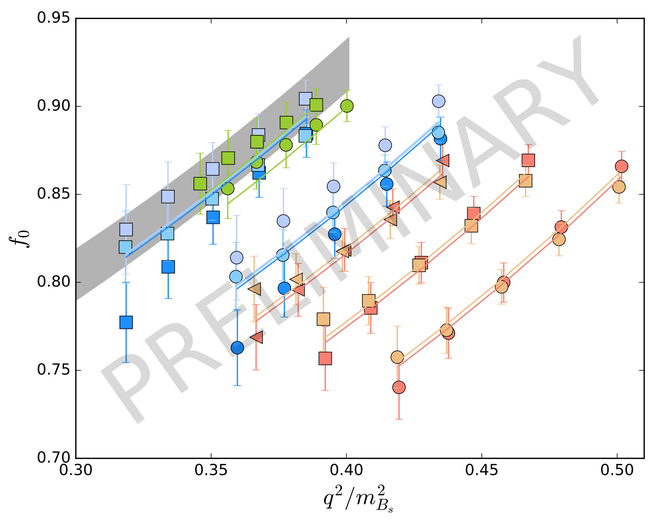
$$z(q^2, t_0) = \frac{\sqrt{1 - q^2/t_+} - \sqrt{1 - t_0/t_+}}{\sqrt{1 - q^2/t_+} + \sqrt{1 - t_0/t_+}}$$

also going to consider Boyd, Grinstein, and Lebed (BGL) [13] and Caprini, Lellouch, Neubert (CLN) [14] for $b \to c$ decays

$B_s \to D_s \ell\nu$

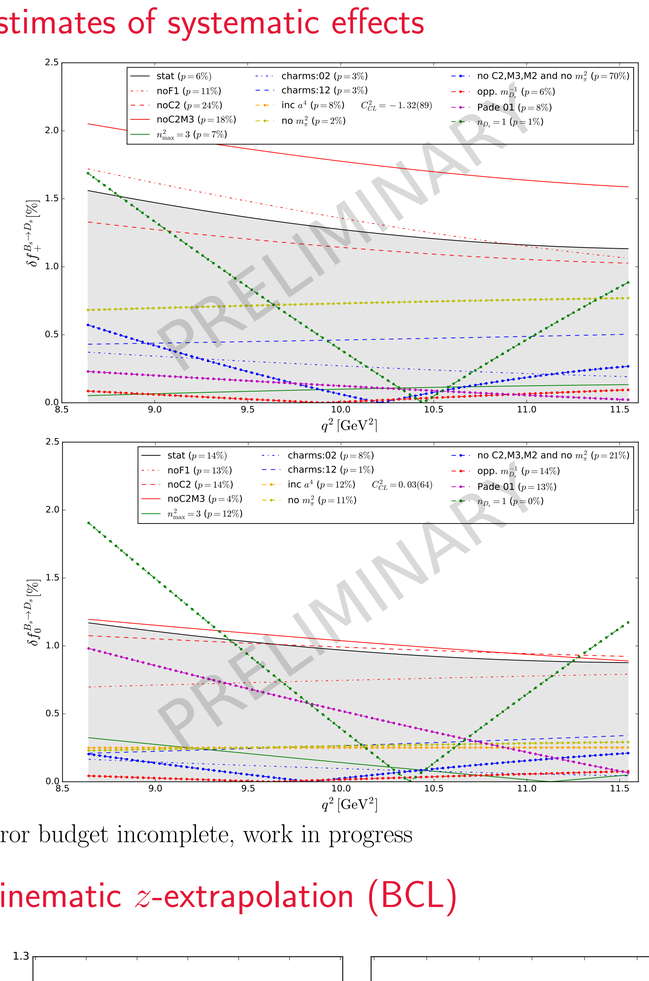
Chiral-charm-continuum extrapolation





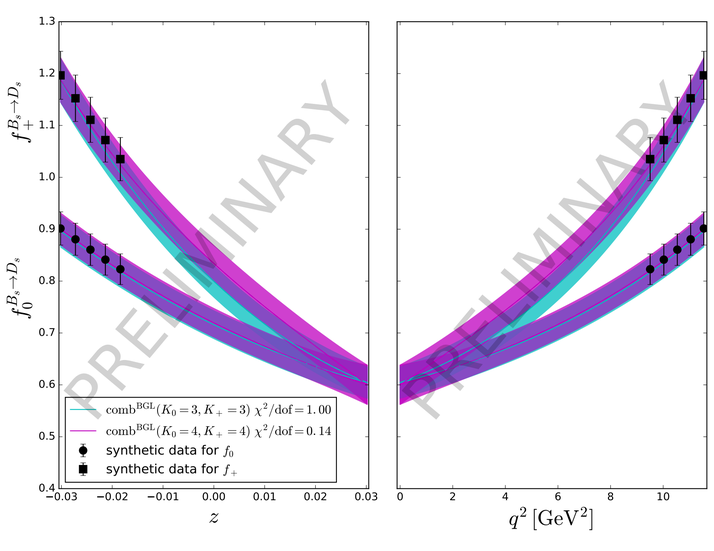
$$f(q^2, a, M_\pi, M_{D_s}) = \frac{\alpha_0 + \alpha_1 M^{-1}_{D_s} + \alpha_2 a^2 + \alpha_3 M^2_\pi}{1 + \alpha_4 q^2/M^2_{B_s}},$$

Estimates of systematic effects



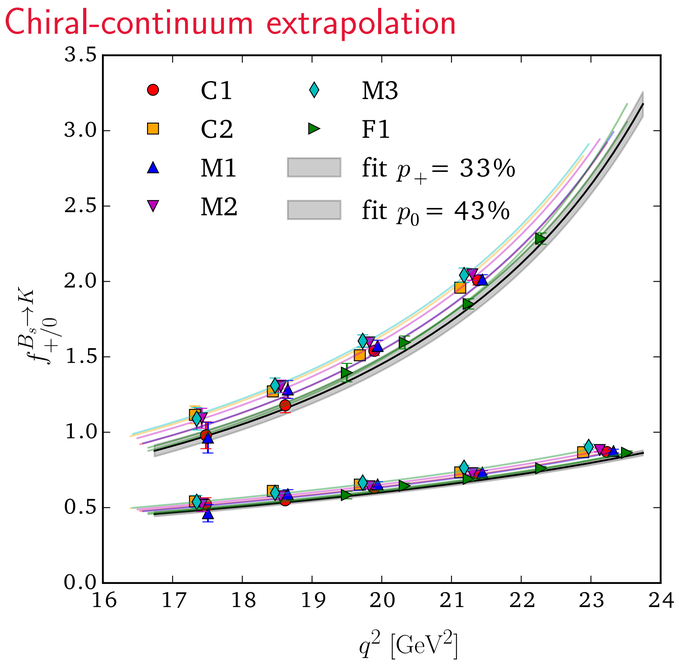
Error budget incomplete, work in progress

Kinematic z-extrapolation (BCL)



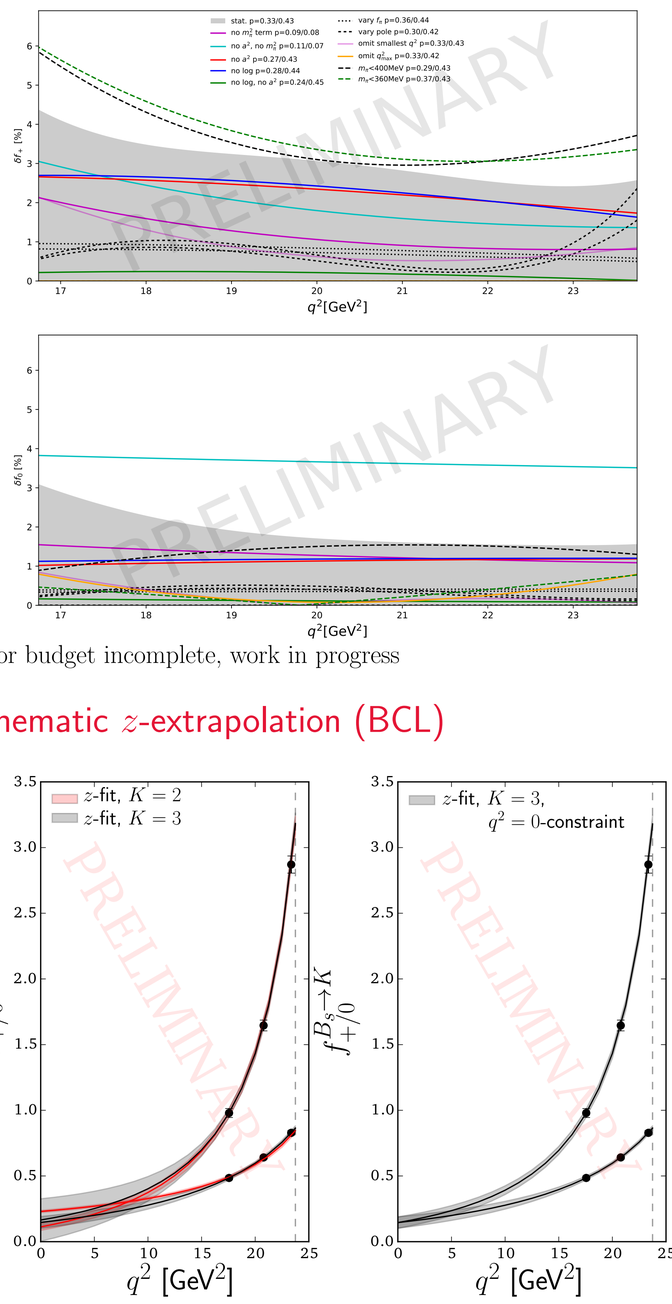
$B_s \to K \ell\nu$

Chiral-continuum extrapolation



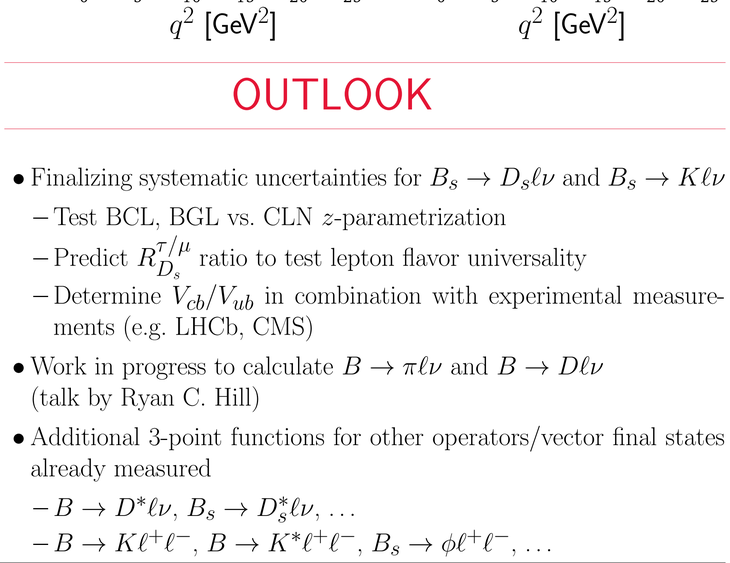
$$f_{\rm pole}(M_K, E_K, a^2) = \frac{1}{E_K + \Delta}c^{(1)} \times \left[1 + \frac{\delta f}{(4\pi f)^2} + c^{(2)}\frac{M^2_K}{\Lambda^2} + c^{(3)}\frac{E_K}{\Lambda} + c^{(4)}\frac{E^2_K}{\Lambda^2} + c^{(5)}\frac{a^2}{\Lambda^2 a^4_{32}}\right]$$

Estimates of systematic effects



Error budget incomplete, work in progress

Kinematic z-extrapolation (BCL)



OUTLOOK

- Finalizing systematic uncertainties for $B_s \to D_s\ell\nu$ and $B_s \to K\ell\nu$
  - Test BCL, BGL vs. CLN z-parametrization
  - Predict $R^{\tau/\mu}_{D_s}$ ratio to test lepton flavor universality
  - Determine V_{cb}/V_{ub} in combination with experimental measurements (e.g. LHCb, CMS)
- Work in progress to calculate $B \to \pi\ell\nu$ and $B \to D\ell\nu$ (talk by Ryan C. Hill)
- Additional 3-point functions for other operators/vector final states already measured
  - $B \to D^*\ell\nu$, $B_s \to D^*_s\ell\nu$, ...
  - $B \to K\ell^+\ell^-$, $B \to K^*\ell^+\ell^-$, $B_s \to \phi\ell^+\ell^-$, ...

REFERENCES

[1] D.B. Kaplan, PLB288(1992)342, arXiv:hep-lat/9206013
[2] Y. Shamir, NPB406(1993)90, arXiv:hep-lat/9303005
[3] V. Furman and Y. Shamir, NPB439(1995)54, arXiv:hep-lat/9405004
[4] R.C. Brower et al., CPC220(2017)1, arXiv:1206.5214 [hep-lat]
[5] P.A. Boyle et al. (UKQCD), JHEP04(2016)037, arXiv:1602.04118 [hep-lat]
[6] H.-W. Lin and N. Christ, PRD76(2007)074506, arXiv:hep-lat/0608005
[7] Y. Aoki et al. (RBC-UKQCD), PRD86(2012)116003, arXiv:1206.2554 [hep-lat]
[8] C. Allton et al. (RBC-UKQCD), PRD78(2008)114509, arXiv:0804.0473 [hep-lat]
[9] Y. Aoki et al. (RBC-UKQCD), PRD83(2011)074508, arXiv:1011.0892 [hep-lat]
[10] T. Blum et al. (RBC-UKQCD), PRD93(2016)074505, arXiv:1411.7017 [hep-lat]
[11] P.A. Boyle et al.(UKQCD), JHEP12(2017)008, arXiv:1701.02644 [hep-lat]
[12] C. Bourrely et al., PRD79(2009)013008, arXiv:0807.2722 [hep-ph]
[13] C.G. Boyd et al., PRL74(1995)4603, arXiv:hep-ph/9412324 [hep-ph]
[14] I. Caprini et al., NPB530(1998)153, arXiv:hep-ph/9712417

Acknowledgment Computations for this work were performed on resources provided by the USQCD Collaboration, funded by the Office of Science of the U.S. Department of Energy, as well as on computers at Columbia University and Brookhaven National Laboratory. This work used the ARCHER UK National Supercomputing Service. Gauge field configurations on which our calculations are based were also generated using the DiRAC Blue Gene Q system at the University of Edinburgh, part of the DiRAC Facility; funded by BIS National E-infrastructure grant ST/K000411/1 and STFC grants ST/H008845/1, ST/K005804/1 and ST/K005790/1.