FPCP Missi-CP 2022

Semileptonic B-decays to excited charmed mesons

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Outline

- Introduction
- QCD Sum Rules
- Results
- Summary & Outlook

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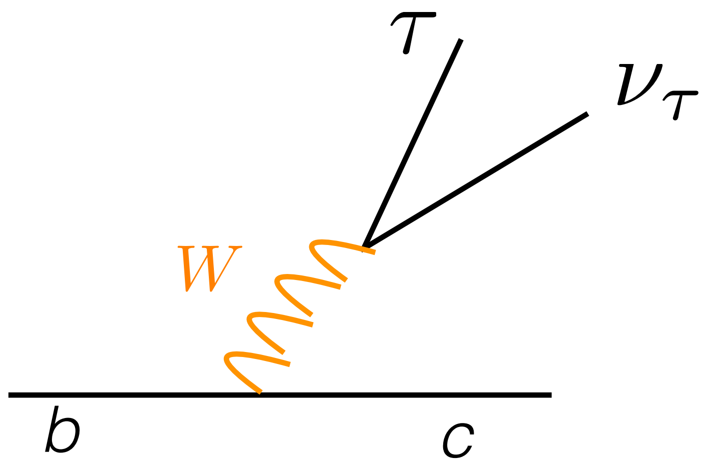
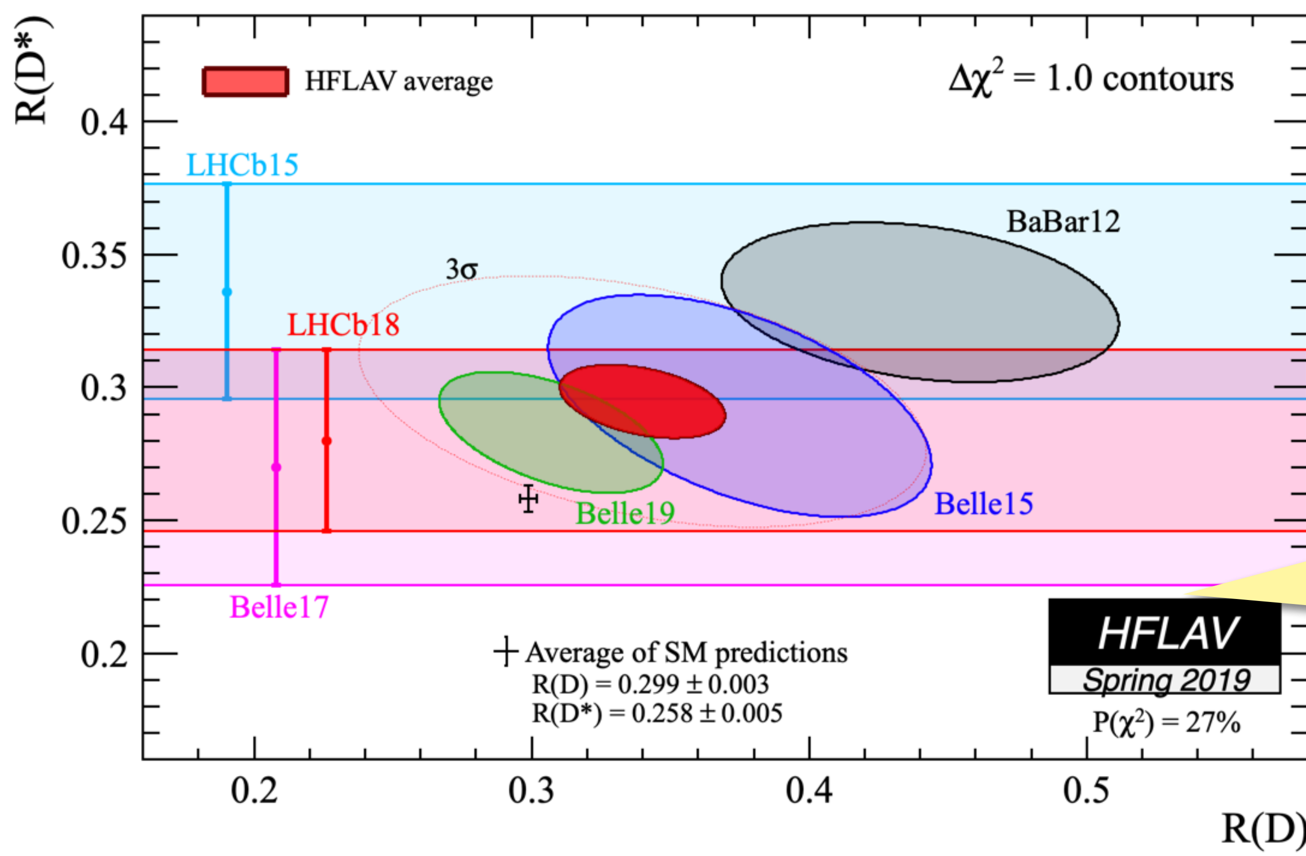
B anomalies

- Exciting discrepancies observed in charged current B decays



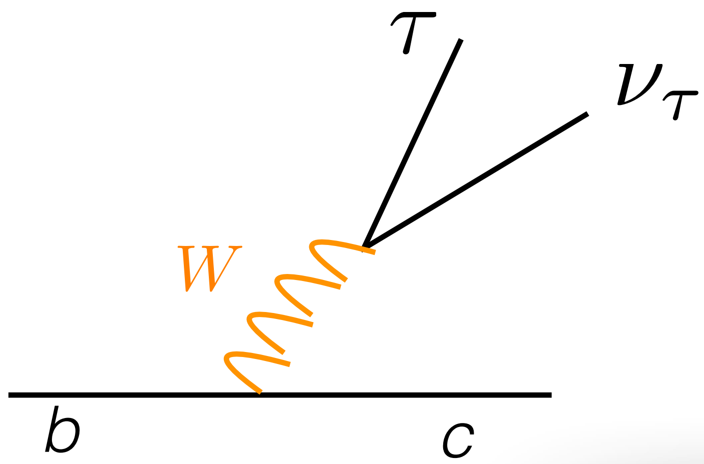
$$R(D^{(*)}) \equiv \frac{\mathrm{BR}(B \to D^{(*)}\tau\nu)}{\mathrm{BR}(B \to D^{(*)}\ell\nu)}, \quad \ell \in \{e, \mu\}$$



combined deviation
$\sim 3\sigma$

B anomalies

- Exciting discrepancies observed in charged current B decays



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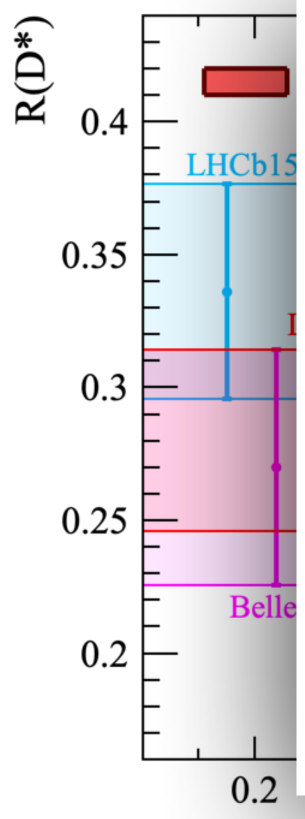


[LHCb,1711.05623]

$$R_{J/\psi} \equiv \frac{\mathrm{BR}(B_c \to J/\psi\, \tau\nu)}{\mathrm{BR}(B_c \to J/\psi\, \mu\nu)}$$

$$= (2.5 \pm 0.97\,) \times R_{J/\psi}^{\mathrm{SM}}$$

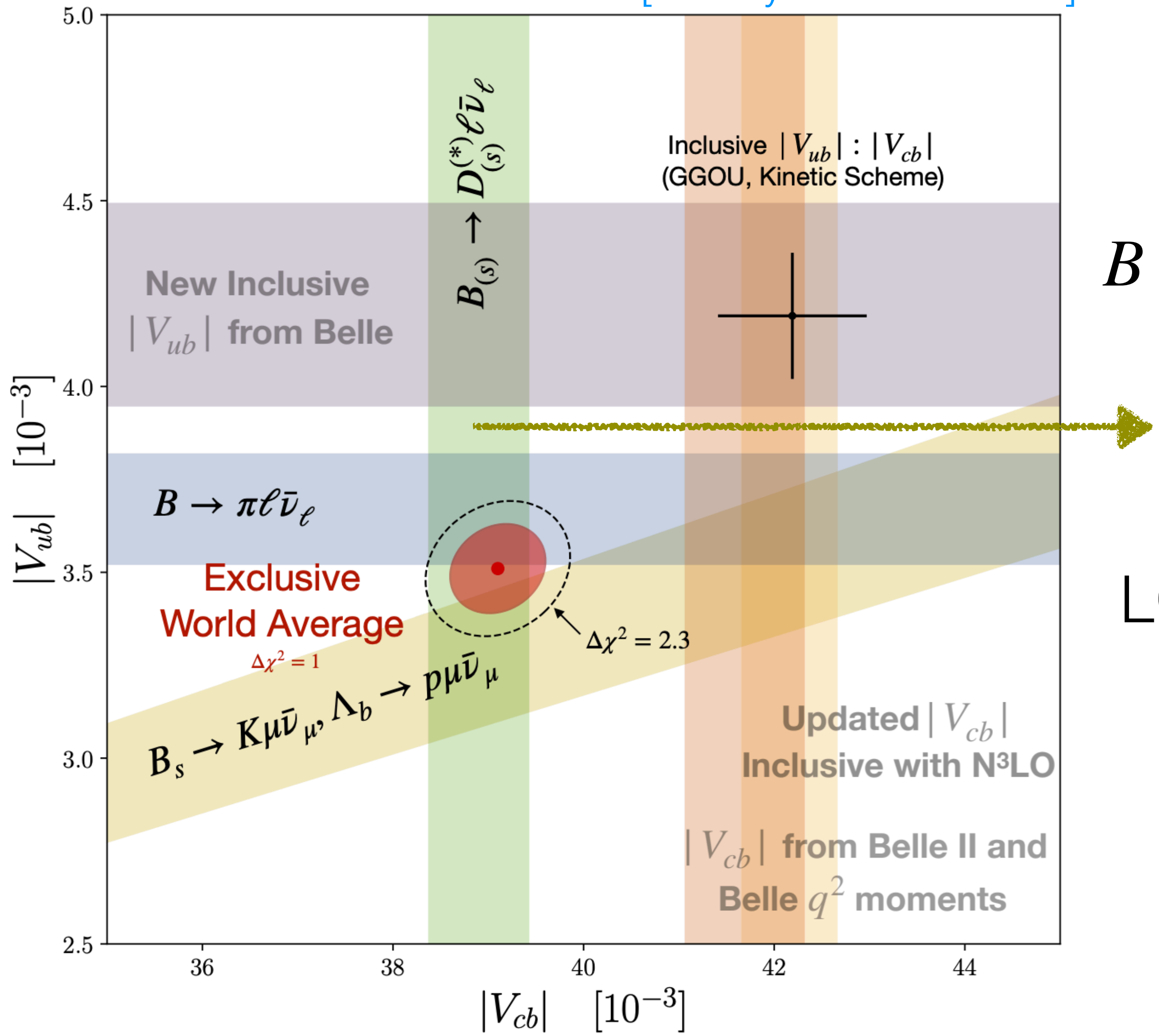
$< 2\sigma$

deviation

V_{cb} puzzle

- Tension between exclusive & inclusive determinations of V_{cb}

[Talk by F. Bernlochner]



$B \to D\ell\nu$, $B \to D^*\ell\nu$, $B_s \to D_s\ell\nu$

measurements

+

Form Factors from

LCSR & several Lattice groups

Excited charmed mesons

Meson	j	J^P	Mass [MeV]	Width [MeV]
$D_0^*(2300)$	$\frac{1}{2}$	0^+	2343 ± 10	229 ± 16
$D_1(2430) \equiv D_1'$	$\frac{1}{2}$	1^+	2412 ± 9	314 ± 29
$D_1(2420) \equiv D_1$	$\frac{3}{2}$	1^+	2422.1 ± 0.6	31.3 ± 1.9
$D_2^*(2460)$	$\frac{3}{2}$	2^+	2461.1 ± 0.8	47.3 ± 0.8

excited mesons provide complementary info.

- New extraction of V_{cb} via $B \to D^{**}$
- Understanding backgrounds for $R(D^{(*)})$ & extraction of V_{ub}
- Gap ~25% between incl. $B \to X_c \ell \nu$ & sum of excl. branching dominated by $D_0, D^*(2007)$

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- Estimate of form factors available only in infinite *c*-quark mass limit [Bernlochner, Ligeti: '16]
- Two 1^+ states are very close in mass & one with large width

QCD sum rules

- QCD Sum Rule methods for non perturbative estimates

Based on Operator product expansion [Shifman *et al.* '79]

Perturbatively calculable amplitudes + Quark & gluon condensate: charactarises QCD vacuum or distribution amplitudes in LCSR [Khodjamirian *et al.* '05,'07]

Dispersion relation

Physical hadronic parameters

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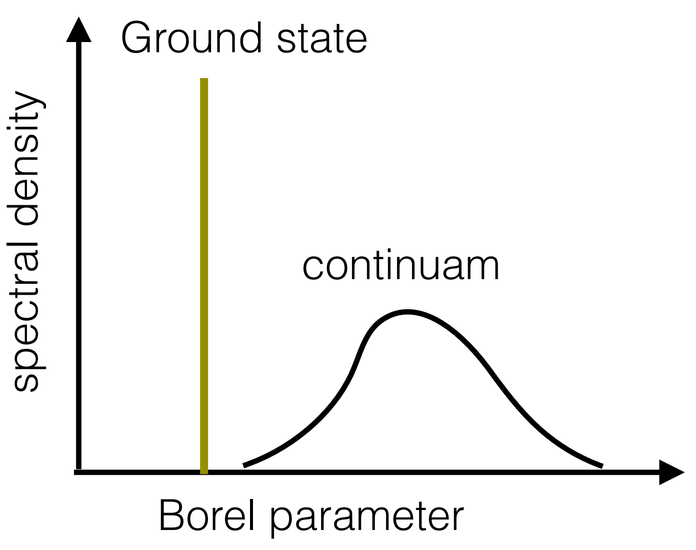
- Limitations: hadronic parameter extraction depends on model ansatzs for the spectrum



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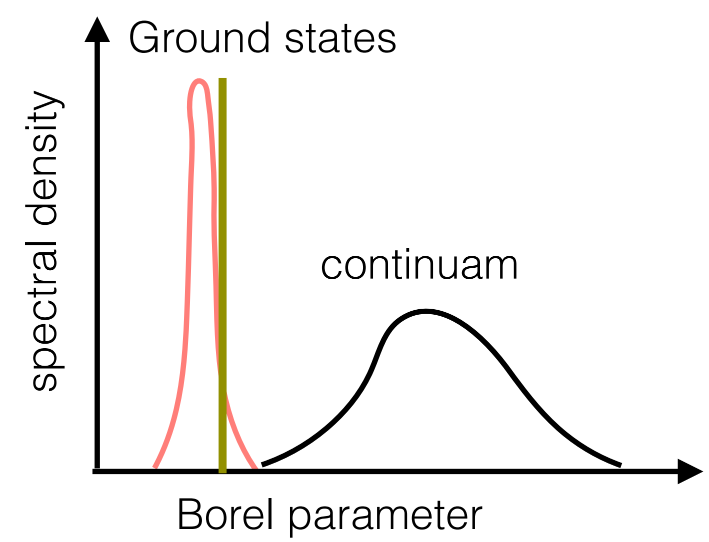

D^{**} mesons

- Correlation function with two independent currents

$$\Pi^{(ij)}_{\mu\nu}(q) = i\int d^4x\, e^{iqx}\langle 0|\mathcal{T}\{J^{(i)}_\mu(x)J^{(j)\dagger}_\nu(0)\}|0\rangle = -g_{\mu\nu}\Pi^{(ij)}(q^2) + q_\mu q_\nu \widetilde{\Pi}^{(ij)}(q^2)$$

$$J^{(1)}_\mu = (m_c + m_q)\bar{c}\gamma_\mu\gamma_5 q$$
$$J^{(2)}_\mu = i\bar{c}\gamma_5 \overleftrightarrow{D}_\mu q\,,$$

} interpolates both 1^+ states simultaneously

0^- contribution

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→ Hadronic representation (contains both states) convoluted with Breit-Wigner form to account for the large width of D_1'

- Matching with OPE: $\Pi^{(ij)}_{\text{OPE}}(q^2) = \Pi^{(ij)}_{\text{pert}}(q^2) + \Pi^{(ij)}_{\text{cond}}(q^2)$

→ Three QCD sum rules with four decay constants

need to rely on external input e.g., Branching Fraction [BABAR '08]

FFs with Light-cone SR

- $B \to D_1^{(\prime)}$ hadronic matrix element in terms of form factors

$$\langle R(p,\varepsilon)|J_\mu^{\rm w}|\bar{B}(p+q)\rangle = -i\varepsilon_\mu^{(R)*}(m_B+m_R)V_1^{BR}(q^2) + i(2p+q)_\mu(\varepsilon^{(R)*}\cdot q)\frac{V_2^{BR}(q^2)}{m_B+m_R}$$
$$+ iq_\mu(\varepsilon^{(R)*}\cdot q)\frac{2m_R}{q^2}\left(V_3^{BR}(q^2) - V_0^{BR}(q^2)\right) - \epsilon_{\mu\nu\alpha\beta}\varepsilon^{(R)*\nu}p^\alpha q^\beta\frac{2A^{BR}(q^2)}{m_B+m_R},$$

where $2m_R V_3^{BR}(q^2) = (m_B+m_R)V_1^{BR}(q^2) - (m_B-m_R)V_2^{BR}(q^2)$ and $V_0^{BR}(0) = V_3^{BR}(0)$

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- Similar process to write LCSRs with correlators

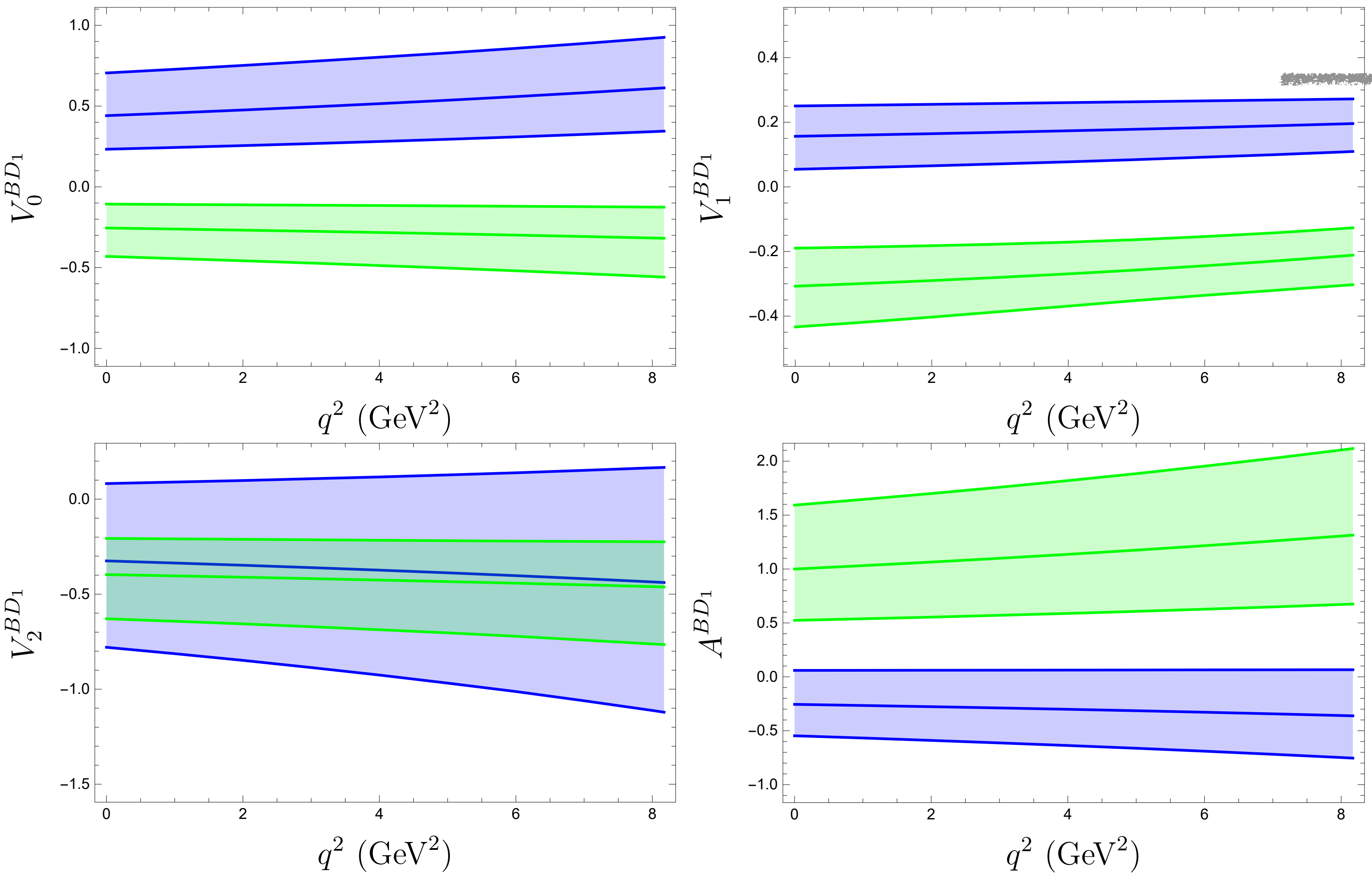
$$\mathcal{F}_{\mu\nu}^{(R)}(p,q) = i\int d^4x\, e^{ip\cdot x}\,\langle 0|\mathcal{T}\left\{J_\nu^{(R)\dagger}(x), J_\mu^{\rm w}(0)\right\}|\bar{B}(p+q)\rangle$$

- Obtained FFs in -ve q^2 extrapolated to +ve region with *z*-expansion

[Bourrely *et al.* '08]

$$z(q^2) = \frac{\sqrt{t_+ - q^2} - \sqrt{t_+ - t_0}}{\sqrt{t_+ - q^2} + \sqrt{t_+ - t_0}} \qquad t_+ = (m_B + m_D)^2$$
$$t_0 = (m_B + m_D)\left(\sqrt{m_B} - \sqrt{m_D}\right)^2$$

$B \to D_1$ Form factors



Large uncertainty (with 2-fold ambiguity)

Lattice inputs on decay constant will help to reduce uncertainty/ambiguity

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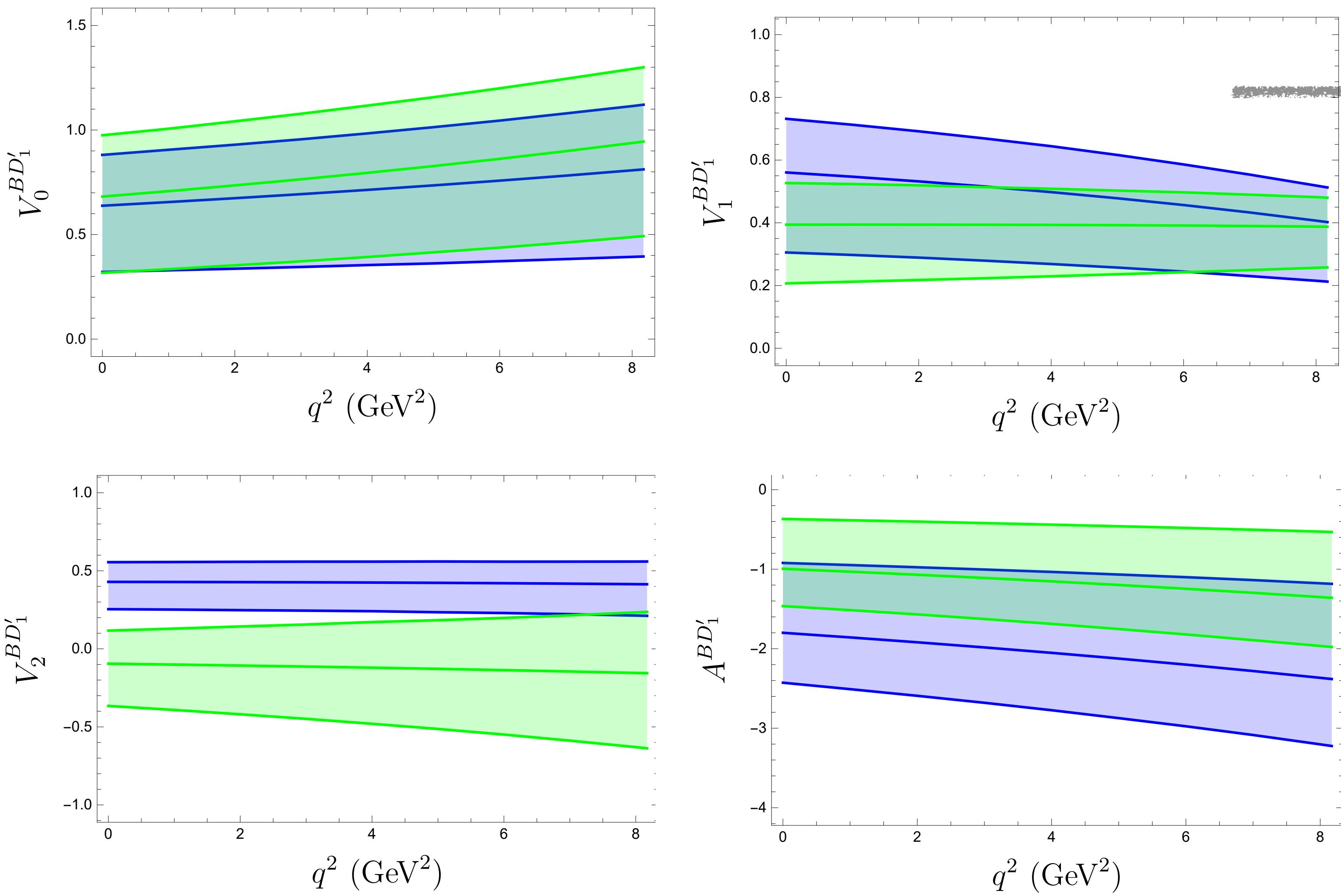

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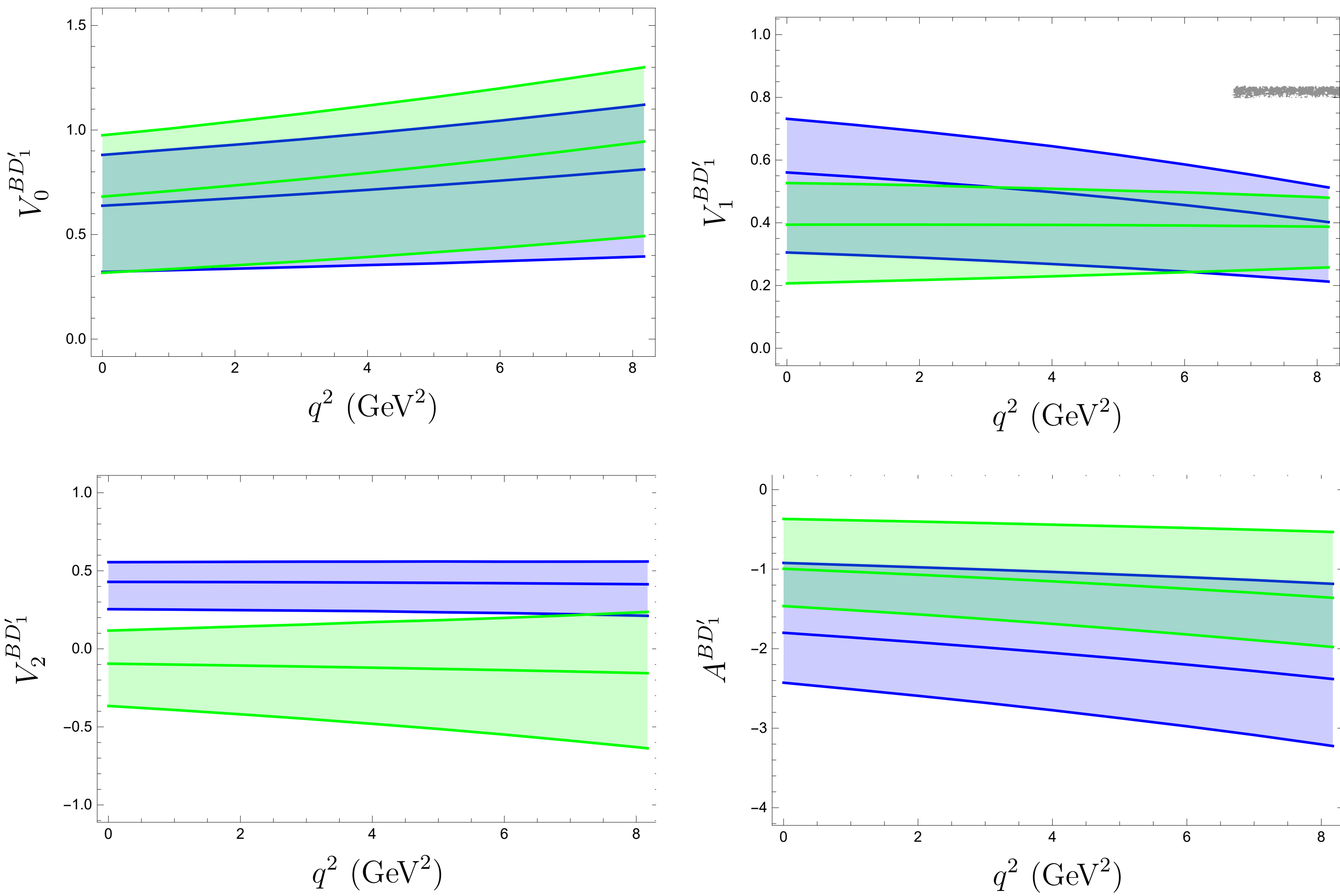

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- Ratio predictions are clean due to cancellations

$$R(D_1) = 0.10 \pm 0.02$$
$$R(D_1') = 0.10 \pm 0.03$$

Summary & Outlook

- $B \to D^{**}\ell\bar{\nu}$ provides complimentary info.

— new V_{cb} extraction

— background estimation for $R(D^{(*)})$ & V_{ub} extraction

⇒ FF shape in full q^2 is important

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- First prediction with finite charm mass is provided for $B \to D_1^{(\prime)}$

Ongoing: $B \to D_0^*$ FFs & $B \to D^*\pi$ partial wave analysis

→ help to understand the gap between inclusive & exclusive channels

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Back ups

FFs

$$F^{BR}(q^2) = \frac{F^{BR}(0)}{1 - \frac{q^2}{m^2_{J^P}}} \left\{1 + \beta_F \left[z(q^2) - z(0)\right]\right\}$$

		$F^{BR}(0)$	β_F	Correlation
sol. 1	A^{BD_1}	-0.27 ± 0.29	-3.15 ± 1.76	0.03
	$V_0^{BD_1}$	0.44 ± 0.20	-3.41 ± 1.26	0.04
	$V_1^{BD_1}$	0.16 ± 0.10	1.69 ± 1.38	0.01
	$V_2^{BD_1}$	-0.32 ± 0.38	-4.19 ± 6.29	0.01
	$A^{BD_1'}$	-1.69 ± 0.77	-1.82 ± 0.74	0.04
	$V_0^{BD_1'}$	0.60 ± 0.32	-0.75 ± 1.21	-0.04
	$V_1^{BD_1'}$	0.53 ± 0.22	9.98 ± 1.05	-0.02
	$V_2^{BD_1'}$	0.40 ± 0.15	5.86 ± 3.42	-0.02
sol. 2	A^{BD_1}	1.00 ± 0.45	-1.82 ± 0.50	-0.06
	$V_0^{BD_1}$	-0.26 ± 0.15	-0.26 ± 1.63	0.02
	$V_1^{BD_1}$	-0.31 ± 0.12	9.32 ± 1.73	-0.02
	$V_2^{BD_1}$	-0.39 ± 0.19	2.26 ± 2.36	0.04
	$A^{BD_1'}$	-0.92 ± 0.61	-3.28 ± 1.26	-0.03
	$V_0^{BD_1'}$	0.66 ± 0.33	-3.71 ± 2.37	0.03
	$V_1^{BD_1'}$	0.37 ± 0.19	3.74 ± 3.25	0.01
	$V_2^{BD_1'}$	-0.12 ± 0.25	-5.84 ± 4.42	0.02