

# PRECISION CALCULATIONS OF THE SEMILEPTONIC $B_q \rightarrow D_q^*$ FORM FACTORS IN SCET

ARXIV: 2301.12391 [HEP-PH]

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THE 5TH HEAVY FLAVOR PHYSICS  
AND QCD WORKSHOP  
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# PRECISION CALCULATIONS OF THE SEMILEPTONIC $B_q \rightarrow D_q^*$ FORM FACTORS IN SCET

## Background of the subject

- The CKM matrix element and  $\mathcal{R}(D^{(*)})$  anomaly
- Research status (LCSR & lattice & exp)

## Research contents

- LCSR for  $B_q \rightarrow D_q^*$  ( $m_c$ ? $m_q$ ?NLP?)
- Combined fit for  $\bar{B}_q \rightarrow D_q^{(*)} \ell \bar{\nu}_\ell$
- Extracting  $|V_{cb}|$  and  $\mathcal{R}(D_{(s)}^{(*)})$

## Summary

# **BACKGROUND OF THE SUBJECT**

# TENSION OF THE CKM MATRIX ELEMENT

- The longstanding tension of  $|V_{cb}|$  from inclusive and exclusive channels:

$$\begin{aligned} |V_{cb}|_{\text{incl}} &= (42.2 \pm 0.8) \times 10^{-3}, \\ |V_{cb}|_{\text{excl}} &= (39.4 \pm 0.8) \times 10^{-3}. \end{aligned} \tag{1}$$

P.A. Zyla et al. (Particle Data Group), PTEP 2022, 083C01 (2022).

- Violation of lepton flavor universality?

Exp

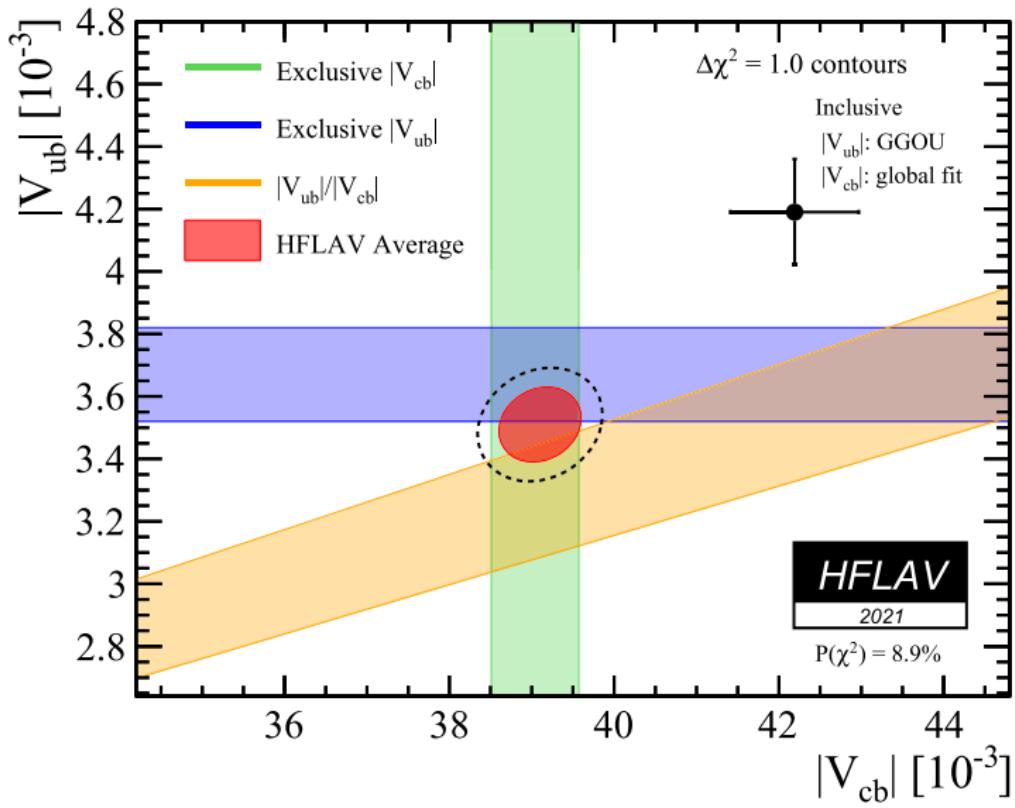
$$R(D) = 0.356 \pm 0.029, \quad R(D^*) = 0.284 \pm 0.013;$$

SM

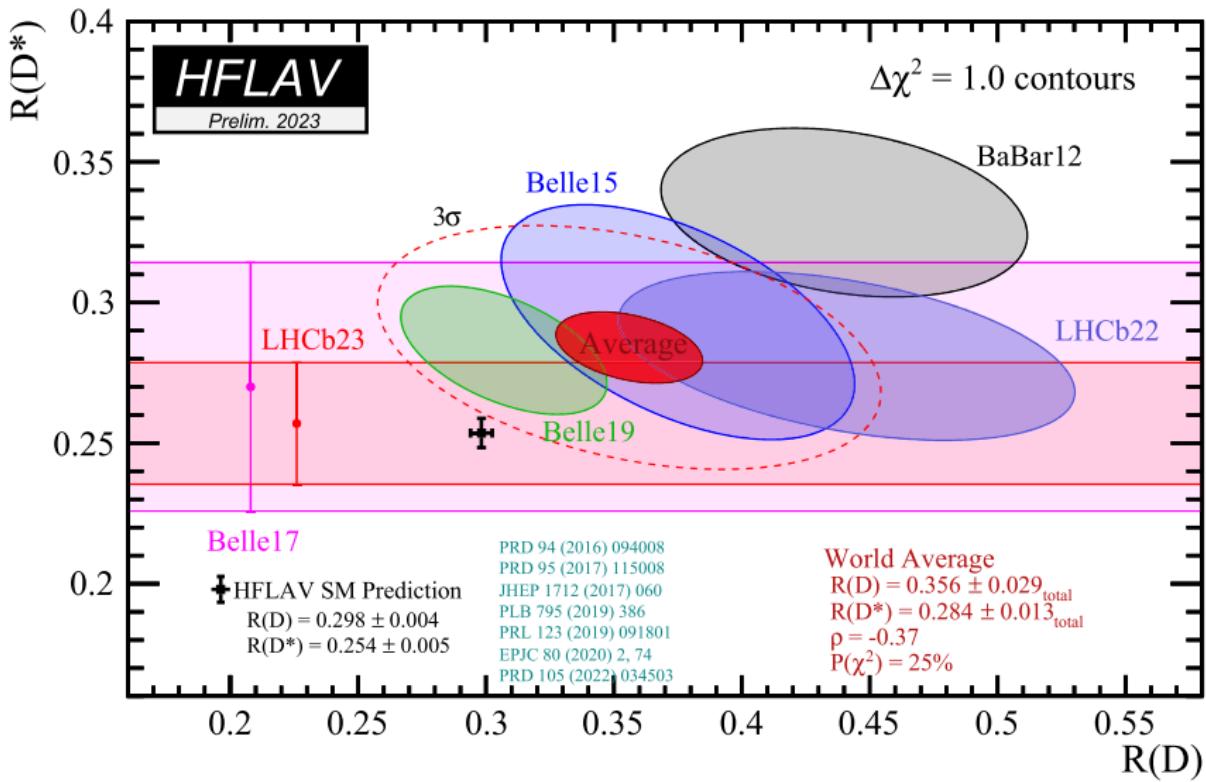
$$R(D) = 0.298 \pm 0.004, \quad R(D^*) = 0.254 \pm 0.005.$$

HFLAV 2023 Averages

# $R(D), R(D^*)$ ANOMALY



# $R(D), R(D^*)$ ANOMALY



# RESEARCH STATUS

## ■ Experiment:

- E. Waheed *et al.* (Belle), PRD 100, 052007 (2019), 1809.03290[hep-ex]
- R. Glattauer *et al.* (Belle), PRD 93, 032006 (2016), 1510.03657[hep-ex]
- F. Abudinén *et al.* (Belle-II), PRD 77 (2008), 032002, 2008.10299[hep-ex]
- J. Lees *et al.* (BaBar), PRL 123, 091801 (2019), 1903.10002[hep-ex]
- R. Aaij *et al.* (LHCb), JHEP 12, 144 (2020), 2003.08453[hep-ex]
- R. Aaij *et al.* (LHCb), PRD 101, 072004 (2020), 2001.03225[hep-ex]

## ■ Lattice QCD:

- J. Harrison and C. T. H. Davies (HPQCD), 2304.03137[hep-lat]
- A. Bazavov *et al.* (FNAL/MILC), EPJC 82, 1141 (2022), 2105.14019[hep-lat]
- J. A. Bailey *et al.* (FNAL/MILC), PRD 92, 034506 (2015), 1503.07237[hep-lat]
- H. Na *et al.* (HPQCD), PRD 92, 054510 (2015), 1505.03925[hep-lat]
- J. Harrison *et al.* (HPQCD), PRD 97 (2018), 054502, 1711.11013[hep-lat]
- J. Harrison *et al.* (HPQCD), PRD 105, 094506 (2022), 2105.11433[hep-lat]
- E. McLean *et al.* (HPQCD), PRD 101, 074513 (2020), 1906.00701[hep-lat]
- J. A. Bailey *et al.* (FNAL/MILC), PRD 86, 039904 (2012), 1202.6346[hep-lat]

## ■ Light Cone Sum Rules:

- J. Gao, T. Huber, Y. Ji, C. Wang, Y. M. Wang and Y. B. Wei, JHEP 05 (2022), 024, 2112.12674 [hep-ph]
- J. Gao, C. D. Lü, Y. L. Shen, Y. M. Wang and Y. B. Wei, PRD 101(2020) 7, 074035, 1907.11092[hep-ph]
- N. Gubernari, A. Kokulu and D. van Dyk, JHEP 01 (2019), 150, 1811.00983[hep-ph]
- S. Faller *et al.*, EPJC 60 (2009) 603-615, 0809.0222[hep-ph]

# **RESEARCH CONTENTS**

$$B \rightarrow D^*$$

## ■ Form factors (QCD)

(a rearrangement of  $V, A_0, A_1, A_2, T_1, T_2, T_3$ )

$$\begin{aligned} \langle D^*(p, \epsilon^*) | \bar{q} \gamma_\mu b | \bar{B}(p+q) \rangle &\longrightarrow \mathcal{V}(q^2), \\ \langle D^*(p, \epsilon^*) | \bar{q} \gamma_\mu \gamma_5 b | \bar{B}(p+q) \rangle &\longrightarrow \mathcal{A}_0(q^2), \mathcal{A}_1(q^2), \mathcal{A}_{12}(q^2), \\ \langle D^*(p, \epsilon^*) | \bar{q} i \sigma_{\mu\nu} q^\nu b | \bar{B}(p+q) \rangle &\longrightarrow \mathcal{T}_1(q^2), \\ \langle D^*(p, \epsilon^*) | \bar{q} i \sigma_{\mu\nu} \gamma_5 q^\nu b | \bar{B}(p+q) \rangle &\longrightarrow \mathcal{T}_2(q^2), \mathcal{T}_{23}(q^2). \end{aligned}$$

- Unphysical singularities at  $q^2 = 0$

$$\mathcal{A}_0(q^2 = 0) = \mathcal{A}_{12}(q^2 = 0). \quad (3)$$

- Algebraic relations between  $\sigma_{\mu\nu}$  and  $\sigma_{\mu\nu}\gamma_5$

$$\mathcal{T}_1(q^2 = 0) = \mathcal{T}_2(q^2 = 0). \quad (4)$$

## ■ SCET<sub>I</sub> Operators containing $m_c$

$$\begin{aligned} O_{||}^{A1, m_c} &\longrightarrow \langle D_q^*(p, \epsilon^*) | (\bar{\xi} W_c) \frac{\not{p}}{2} \frac{m_c}{-in \cdot \not{D}_c} \gamma_5 h_v | \bar{B}_v \rangle = -n \cdot p (\epsilon^* \cdot v) \xi_{||, m_c}(p_+), \\ O_{\perp}^{A1, m_c} &\longrightarrow \langle D_q^*(p, \epsilon^*) | (\bar{\xi} W_c) \frac{\not{p}}{2} \frac{m_c}{-in \cdot \not{D}_c} \gamma_5 \gamma_{\mu\perp} h_v | \bar{B}_v \rangle = -n \cdot p (\epsilon_\mu^* - \epsilon^* \cdot v \bar{n}_\mu) \xi_{\perp, m_c}(p_+). \end{aligned} \quad (5)$$

$$B \rightarrow D^*$$

■ “QCD  $\rightarrow$  SCET<sub>I</sub>”  $\Rightarrow$  6 form factors

$$p_+ \equiv n \cdot p$$

$$\begin{aligned} \mathcal{V}(p_+) &= C_V^{(A_0)}(p_+) \xi_{\perp}(p_+) + C_V^{(A_1, m_c)}(p_+) \xi_{\perp, m_c}(p_+) + C_V^{(B_1)}(\tau, p_+) \otimes_{\tau} \Xi_{\perp}(\tau, p_+) + \mathcal{V}^{\text{NLP}}(p_+), \\ \mathcal{A}_0(p_+) &= C_{f_0}^{(A_0)}(p_+) \xi_{\parallel}(p_+) + C_{f_0}^{(A_1, m_c)}(p_+) \xi_{\parallel, m_c}(p_+) + C_{f_0}^{(B_1)}(\tau, p_+) \otimes_{\tau} \Xi_{\parallel}(\tau, p_+) + \mathcal{A}_0^{\text{NLP}}(p_+), \\ \mathcal{A}_1(p_+) &= C_V^{(A_0)}(p_+) \xi_{\perp}(p_+) + C_{A_1}^{(A_1, m_c)}(p_+) \xi_{\perp, m_c}(p_+) + C_V^{(B_1)}(\tau, p_+) \otimes_{\tau} \Xi_{\perp}(\tau, p_+) + \mathcal{A}_1^{\text{NLP}}(p_+), \\ \mathcal{A}_{12}(p_+) &= C_{f_+}^{(A_0)}(p_+) \xi_{\parallel}(p_+) + C_{f_+}^{(A_1, m_c)}(p_+) \xi_{\parallel, m_c}(p_+) + C_{f_+}^{(B_1)}(\tau, p_+) \otimes_{\tau} \Xi_{\parallel}(\tau, p_+) + \mathcal{A}_{12}^{\text{NLP}}(p_+), \\ \mathcal{T}_1(p_+) &= C_{T_1}^{(A_0)}(p_+) \xi_{\perp}(p_+) + C_{T_1}^{(A_1, m_c)}(p_+) \xi_{\perp, m_c}(p_+) + C_{T_1}^{(B_1)}(\tau, p_+) \otimes_{\tau} \Xi_{\perp}(\tau, p_+) + \mathcal{T}_1^{\text{NLP}}(p_+), \\ \mathcal{T}_2(p_+) &= C_{T_1}^{(A_0)}(p_+) \xi_{\perp}(p_+) + C_{T_2}^{(A_1, m_c)}(p_+) \xi_{\perp, m_c}(p_+) + C_{T_1}^{(B_1)}(\tau, p_+) \otimes_{\tau} \Xi_{\perp}(\tau, p_+) + \mathcal{T}_2^{\text{NLP}}(p_+), \\ \mathcal{T}_{23}(p_+) &= C_{f_T}^{(A_0)}(p_+) \xi_{\parallel}(p_+) + C_{f_T}^{(A_1, m_c)}(p_+) \xi_{\parallel, m_c}(p_+) + C_{f_T}^{(B_1)}(\tau, p_+) \otimes_{\tau} \Xi_{\parallel}(\tau, p_+) + \mathcal{T}_{23}^{\text{NLP}}(p_+). \end{aligned} \tag{6}$$

■ Hard Matching Coefficients for  $\xi_{m_c}$

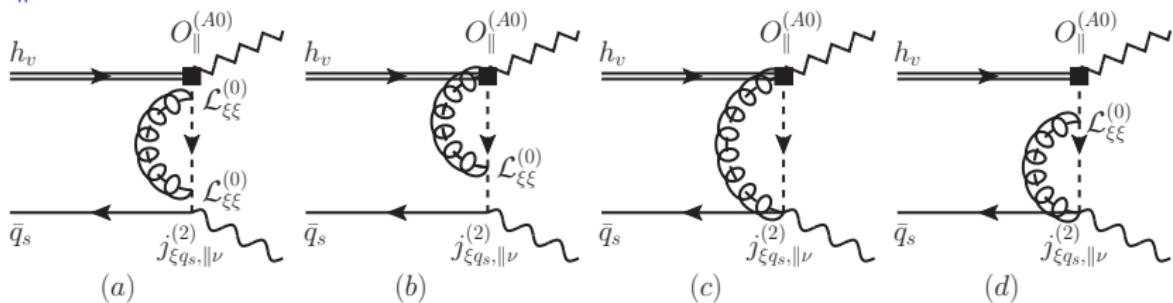
$$(r \equiv p_+/m_b)$$

$$\begin{aligned} C_{f_+}^{(A_1 m)} &= r - 1 + \mathcal{O}(\alpha_s), & C_{f_0}^{(A_1 m)} &= 1 - r + \mathcal{O}(\alpha_s), & C_{f_T}^{(A_1 m)} &= -1 + \mathcal{O}(\alpha_s), \\ C_V^{(A_1 m)} &= -1 + \mathcal{O}(\alpha_s), & C_{A_1}^{(A_1 m)} &= 1 + \mathcal{O}(\alpha_s), & C_{T_1}^{(A_1 m)} &= -1 + \mathcal{O}(\alpha_s), \\ C_{T_2}^{(A_1 m)} &= 1 + \mathcal{O}(\alpha_s). \end{aligned} \tag{7}$$

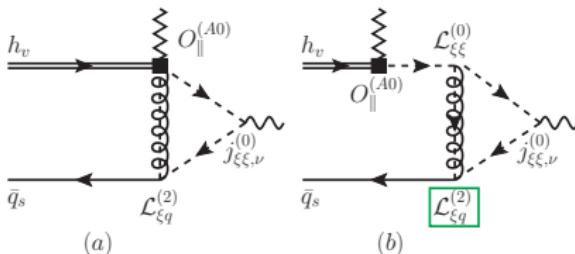
# $B \rightarrow V$ (PARALLEL PART)

■ Leading Power, Next-to-Leading Order (SCET<sub>I</sub>)

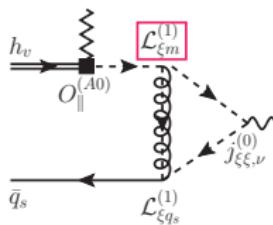
$\xi_{\parallel}$  part-A



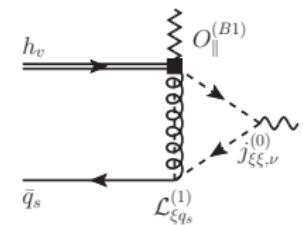
$\xi_{\parallel}$  part-B



$\xi_{\parallel}$  part-C



$\Xi_{\parallel}$



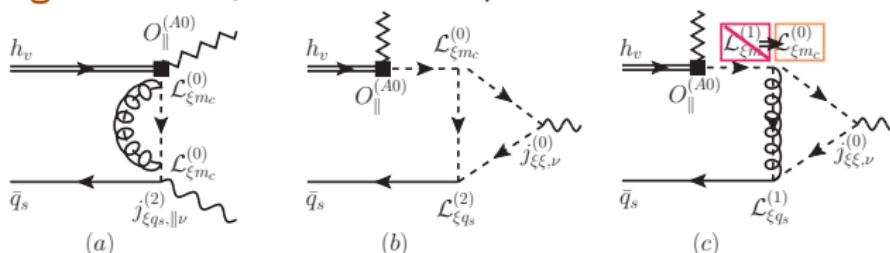
Replacing the parallel operator into the corresponding transverse one, provides the transverse part.

# $B_q \rightarrow D_q^*$ (ADDITIONAL PARALLEL PART)

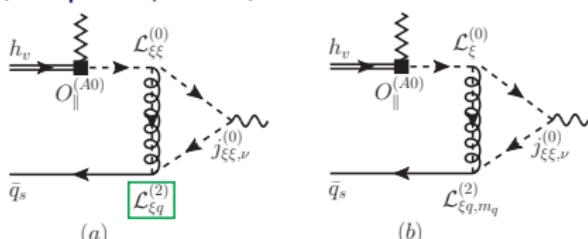
■ SCET<sub>I</sub> Lagrangian with  $m_c \sim \mathcal{O}(\sqrt{\Lambda_{\text{QCD}} m_b})$ ,  $m_q \sim \mathcal{O}(\Lambda_{\text{QCD}})$

$$\begin{aligned}\mathcal{L}_{\xi m_c}^{(0)} &= m_c \bar{\xi} \left[ i \not{D}_{\perp c}, \frac{1}{in \cdot D_c} \right] \frac{\not{p}}{2} \xi - m_c^2 \bar{\xi} \frac{1}{in \cdot D_c} \frac{\not{p}}{2} \xi, \\ \mathcal{L}_{\xi q, m_q}^{(2)} &= -m_q \left[ (\bar{\xi} W_c)(Y_s^\dagger q_s) + (\bar{q}_s Y_s)(W_c^\dagger \xi) \right].\end{aligned}\quad (8)$$

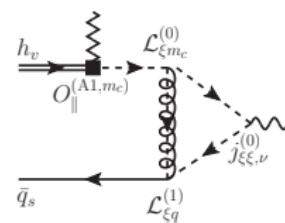
►  $m_c$  Lagrangian (a b new, c enhanced from part-C)



►  $m_q$  contribution  
(a in part-B; b new)



►  $\mathcal{O}_{||}^{(A1, m_c)}$  contribution



$\mathcal{O}_{\perp}^{(A1, m_c)}$  contribute  $\mathcal{O}(\varepsilon)$ , just as  $\xi_{\perp}$  part-C.

$$B_q \rightarrow D_q^* \text{ NLP}$$

## ■ Vacuum-to- $B$ -meson correlation functions

$$\begin{aligned}\Pi_{\mu,||}^{(a)}(p, q) &= \int d^4x e^{ip \cdot x} \langle 0 | T\{ j_{||}^V(x), \bar{q}(0) \Gamma_\mu^{(o)} b(0) \} | \bar{B}_q(p+q) \rangle, \\ \Pi_{\delta\mu,\perp}^{(a)}(p, q) &= \int d^4x e^{ip \cdot x} \langle 0 | T\{ j_{\delta,\perp}^V(x), \bar{q}(0) \Gamma_\mu^{(o)} b(0) \} | \bar{B}_q(p+q) \rangle.\end{aligned}\quad (9)$$

$$j_{||}^V(x) = \bar{q}'(x) \frac{\not{p}}{2} q(x), \quad j_{\delta,\perp}^V(x) = \bar{q}'(x) \frac{\not{p}}{2} \gamma_{\delta,\perp} q(x); \quad \Gamma_\mu^{(a)} \in \{ \gamma_\mu (1 - \gamma_5), i\sigma_{\mu\nu}(1 + \gamma_5)q^\nu \}.$$

## ■ Heavy Quark Effective Theory contribution

$$b \rightarrow h_v + \frac{i\cancel{p}}{2m_b} h_v + \mathcal{O}(\lambda^2). \quad (10)$$

## ■ $c$ -quark propagator

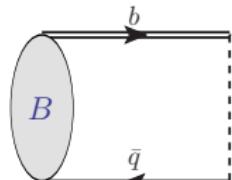
$$\frac{\cancel{p} - \cancel{k} + m_c}{(p-k)^2 - m_c^2} \rightarrow \left( \underbrace{\cancel{p}}_{\mathcal{O}(\lambda^0)} - \underbrace{\cancel{k}}_{\mathcal{O}(\lambda^1)} + \underbrace{m_c}_{\mathcal{O}(\lambda^{1/2})} \right) \left( \underbrace{\frac{1}{n \cdot p \bar{n} \cdot (p-k) - m_c^2}}_{\mathcal{O}(\lambda^{-1})} + \underbrace{\frac{n \cdot k \bar{n} \cdot p}{(n \cdot p \bar{n} \cdot (p-k) - m_c^2)^2}}_{\mathcal{O}(\lambda^0)} \right) + \dots \quad (11)$$

$$B_q \rightarrow D_q^* \text{ NLP}$$

## ■ Higher-twist contributions

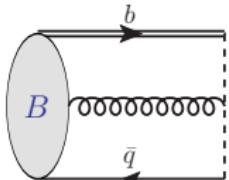
### ► 2-Particle Light Cone Distribution Amplitudes

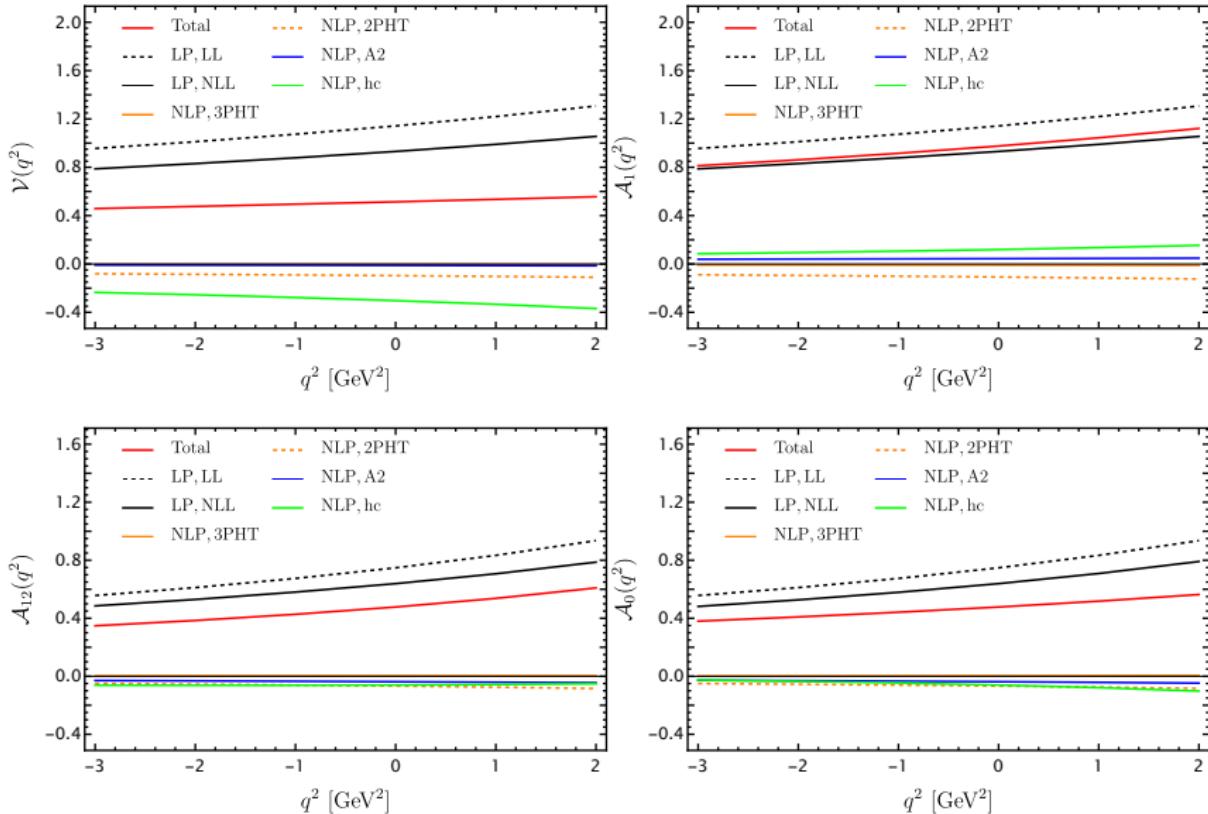
$$\begin{aligned} & \langle o | (\bar{q} Y_s)_\beta(x) (Y_s^\dagger h_v)_\alpha(o) | \bar{B}(v) \rangle \\ &= -\frac{i \tilde{f}_B(\mu) m_B}{4} \int_0^\infty d\omega e^{-i\omega v \cdot x} \left[ \frac{1+\gamma}{2} \left\{ 2 \left( \phi_B^+(\omega) + x^2 g_B^+(\omega) \right) \right. \right. \\ & \quad \left. \left. - \frac{\not{x}}{v \cdot x} \left[ \left( \phi_B^+(\omega) - \phi_B^-(\omega) \right) + x^2 \left( g_B^+(\omega) - g_B^-(\omega) \right) \right] \right\} \gamma_5 \right]_{\alpha\beta}. \quad (12) \end{aligned}$$



### ► 3-Particle Light Cone Distribution Amplitudes

$$\begin{aligned} & \langle o | \bar{q}(z_1 \bar{n}) [z_1 \bar{n}, z_2 \bar{n}] g_s G_{\mu\nu}(z_2 \bar{n}) \Gamma [z_2 \bar{n}, o] h_v(o) | \bar{B}_v \rangle \\ &= \frac{1}{2} \tilde{f}_B(\mu) m_B \text{Tr} \left\{ \gamma_5 \Gamma P_+ \left[ (v_\mu \gamma_\nu - v_\nu \gamma_\mu) [\Psi_A - \Psi_V] - i \sigma_{\mu\nu} \Psi_V \right. \right. \\ & \quad \left. \left. - (\bar{n}_\mu v_\nu - \bar{n}_\nu v_\mu) X_A + (\bar{n}_\mu \gamma_\nu - \bar{n}_\nu \gamma_\mu) [W + Y_A] - i \epsilon_{\mu\nu\alpha\beta} \bar{n}^\alpha v^\beta \gamma_5 \tilde{X}_A \right. \right. \\ & \quad \left. \left. + i \epsilon_{\mu\nu\alpha\beta} \bar{n}^\alpha \gamma^\beta \gamma_5 \tilde{Y}_A - (\bar{n}_\mu v_\nu - \bar{n}_\nu v_\mu) \not{p} W + (\bar{n}_\mu \gamma_\nu - \bar{n}_\nu \gamma_\mu) \not{p} Z \right] \right\} (z_1, z_2; \mu). \quad (13) \end{aligned}$$





# RESEARCH CONTENTS

**COMBINED FIT FOR  $\bar{B}_q \rightarrow D_q^{(*)} \ell \bar{\nu}_\ell$**

## ■ Boyd-Grinstein-Lebed parameterization



$$\begin{aligned} \langle D_q^*(p', \epsilon) | V^\mu | \bar{B}_q(p) \rangle &= -ig \epsilon^{\mu\alpha\beta\gamma} \epsilon_\alpha^* p'_\beta p_\gamma, \\ \langle D_q^*(p', \epsilon) | A^\mu | \bar{B}_q(p) \rangle &= f \epsilon^{*\mu} + (\epsilon^* \cdot p)[\mathbf{a}_+(p + p')^\mu + \mathbf{a}_-(p - p')^\mu], \\ \mathcal{F}_1(t) &\equiv \frac{1}{m} \left[ 2k^2 t \mathbf{a}_+(t) - \frac{1}{2}(t - M^2 + m^2) \mathbf{f}(t) \right], \\ \mathcal{F}_2(t) &\equiv \frac{1}{m} \left[ \mathbf{f}(t) + (M^2 - m^2) \mathbf{a}_+(t) + t \mathbf{a}_-(t) \right]. \end{aligned} \quad (14)$$

▶  $q^2 \rightarrow z$

$$z(q^2) \equiv z(q^2, t_-) = \frac{\sqrt{t_+ - q^2} - \sqrt{t_+ - t_-}}{\sqrt{t_+ - q^2} + \sqrt{t_+ - t_-}}, \quad t_\pm = (m_{B^{(*)}} \pm m_{D^{(*)}})^2. \quad (15)$$



$$\begin{aligned} \mathbf{g} &= \frac{1}{P_{1^-}(z)\phi_g(z)} \sum_{j=0}^{\infty} a_j \mathbf{z}^j, & \mathbf{f} &= \frac{1}{P_{1^+}(z)\phi_f(z)} \sum_{j=0}^{\infty} b_j \mathbf{z}^j, \\ \mathcal{F}_1 &= \frac{1}{P_{1^+}(z)\phi_{\mathcal{F}_1}(z)} \sum_{j=0}^{\infty} c_j \mathbf{z}^j, & \mathcal{F}_2 &= \frac{1}{P_{0^-}(z)\phi_{\mathcal{F}_2}(z)} \sum_{j=0}^{\infty} d_j \mathbf{z}^j. \end{aligned} \quad (16)$$

C. G. Boyd, B. Grinstein and R. F. Lebed, 9705252[hep-ph]

## ■ FFs in BGL and QCD

▶

$$g = \frac{2}{m_{B_q}(1 + r_q)} V,$$

$$f = m_{B_q}(1 + r_q) A_1,$$

$$\mathcal{F}_1 = m_{B_q}^2(1 + \omega) \left[ \frac{1 + r_q}{1 + \omega} (\omega - r_q) A_1 + \frac{2r_q}{1 + r_q} (1 - \omega) A_2 \right], \quad (17)$$

$$\mathcal{F}_2 = 2A_0,$$

$$\omega = \frac{m_{B_q}^2 + m_{D_q^*}^2 - q^2}{2B_q m_{D_q^*}}, \quad r_q = \frac{m_{D_q^*}}{m_{B_q}}.$$

### ► Constraints

eq(18) derived from eq(3), eq(19) trivially from the definition

$$\mathcal{F}_2(\omega_{\max}) = \frac{1 + r_q}{m_{B_q}^2(1 + \omega_{\max})(1 - r_q)r_q} \mathcal{F}_1(\omega_{\max}), \quad (18)$$

$$\mathcal{F}_1(\omega = 1) = m_{B_q}(1 - r_q)f(\omega = 1). \quad (19)$$

# (Strong) BOUND

## ■ Strong Unitarity Bound

- Include all  $B_q^{(*)} \rightarrow D_q^{(*)}$  channels with quantum numbers  $0^+, 0^-, 1^-, 1^+$ .

$$\begin{aligned}
 & \sum_{i=1}^3 \sum_{n=0}^N (a_n^{S_i})^2 < 1, & \sum_{i=1}^3 \sum_{n=0}^N (a_n^{P_i})^2 < 1, \\
 & \sum_{i=1}^7 \sum_{n=0}^N (a_n^{V_i})^2 < 1, & \sum_{i=1}^7 \sum_{n=0}^N (a_n^{A_i})^2 < 1.
 \end{aligned} \tag{20}$$

	$B_q \rightarrow D_q$	$B_q \rightarrow D_q^*$	$B_q^* \rightarrow D_q$	$B_q^* \rightarrow D_q^*$
$V, 1^-$	$f_+$	$g$	$\hat{g}$	$V_{+0}, V_{++}, V_{0+}, V_{00}$
$A, 1^+$	-	$f, \mathcal{F}_1$	$\hat{f}, \hat{\mathcal{F}}_1$	$A_{++}, A_{+0}, A_{0+}$
$S, 0^+$	$f_0$	-	-	$S_{0+}, S_{00}$
$P, 0^-$	-	$\mathcal{F}_2$	$\hat{\mathcal{F}}_2$	$P_{0+}$

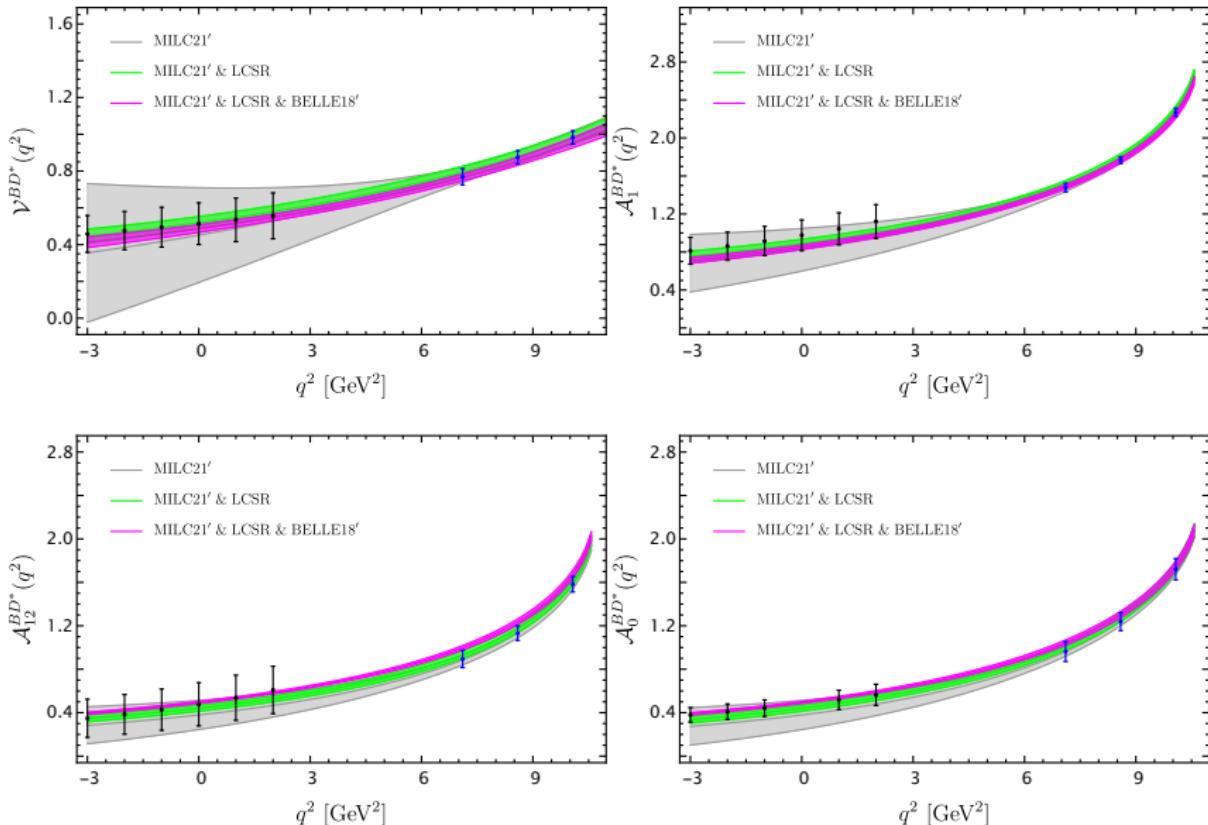
# DATA

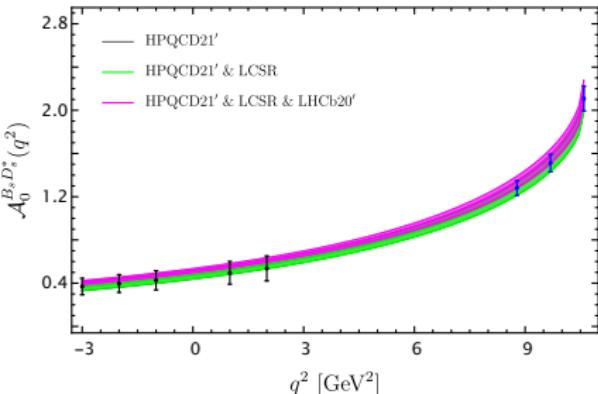
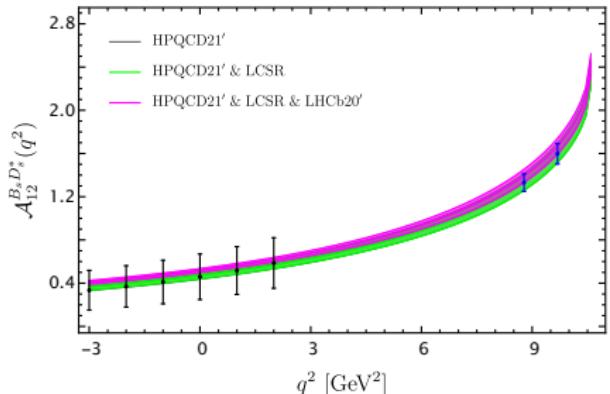
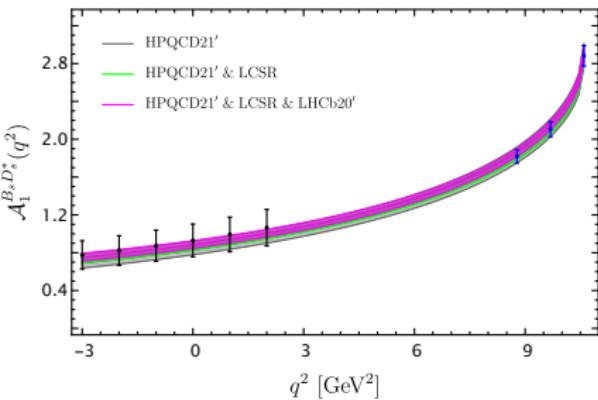
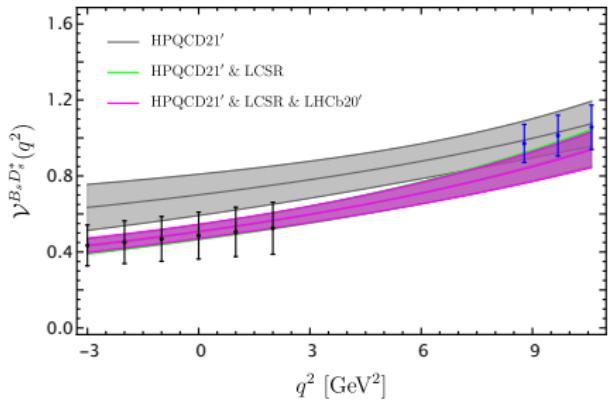
## ■ LQCD and Experiment ( $B_{(q)} \rightarrow D_{(q)}^{(*)}$ )

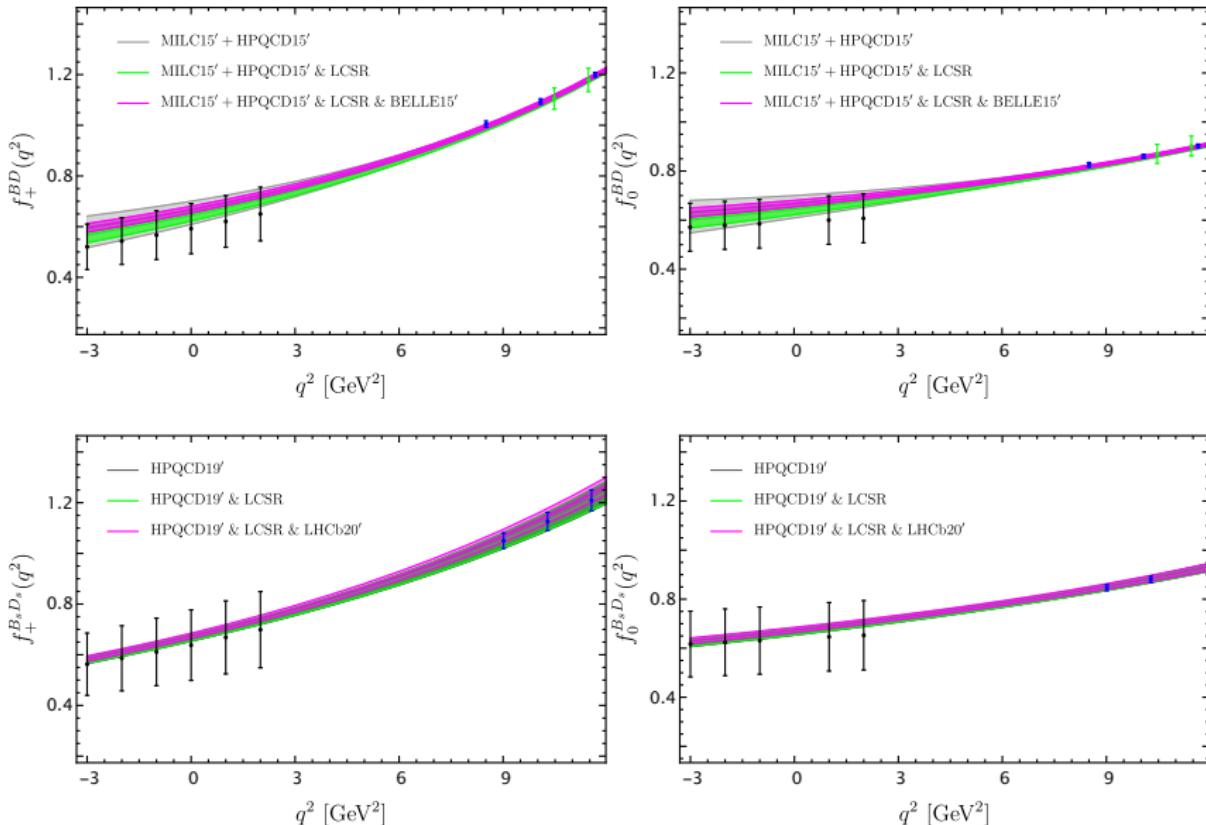
	$B \rightarrow D$	$B \rightarrow D^*$	$B_s \rightarrow D_s$	$B_s \rightarrow D_s^*$
LQCD	MILC15,HPQCD15	MILC21	MILC12,HPQCD19	HPQCD21
Exp.	Belle15	Belle18	LHCb20	LHCb20,21

## ■ LCSR ( $B_{(q)} \rightarrow D_{(q)}^*$ )

$q^2(\text{GeV})$	-3.0	-2.0	-1.0	0.0	1.0	2.0
$V^{BD^*}$	0.633(138)	0.657(144)	0.683(149)	0.710(156)	0.738(163)	0.768(172)
$A_1^{BD^*}$	0.661(115)	0.676(115)	0.691(116)	0.707(117)	0.724(117)	0.743(117)
$A_2^{BD^*}$	0.750(169)	0.770(175)	0.788(181)	0.805(188)	0.818(196)	0.827(205)
$A_0^{BD^*}$	0.561(098)	0.582(101)	0.604(104)	0.627(108)	0.651(112)	0.677(117)
$V^{B_s D_s^*}$	0.606(150)	0.629(156)	0.653(164)	0.678(172)	0.704(181)	0.731(191)
$A_1^{B_s D_s^*}$	0.625(120)	0.638(121)	0.652(123)	0.667(124)	0.683(125)	0.700(126)
$A_2^{B_s D_s^*}$	0.729(176)	0.747(183)	0.763(190)	0.776(199)	0.785(208)	0.789(219)
$A_0^{B_s D_s^*}$	0.526(109)	0.545(113)	0.564(117)	0.583(122)	0.604(128)	0.625(134)

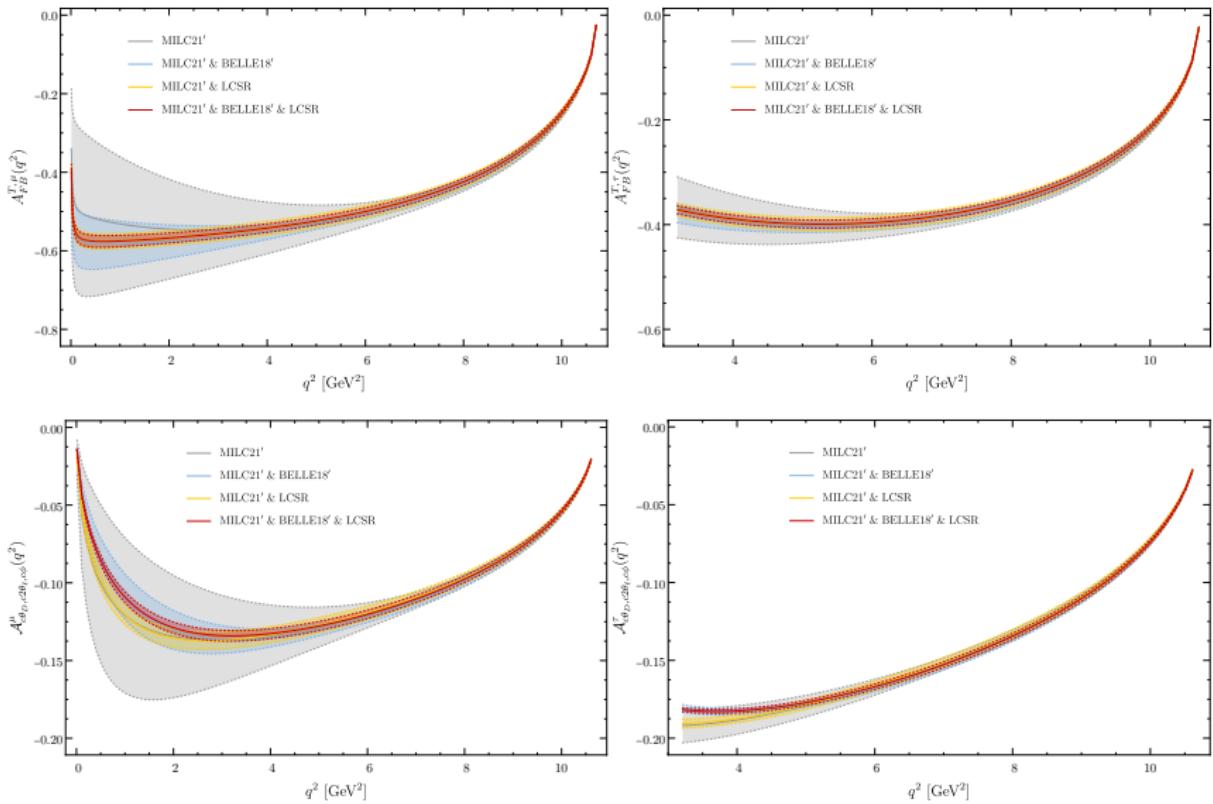


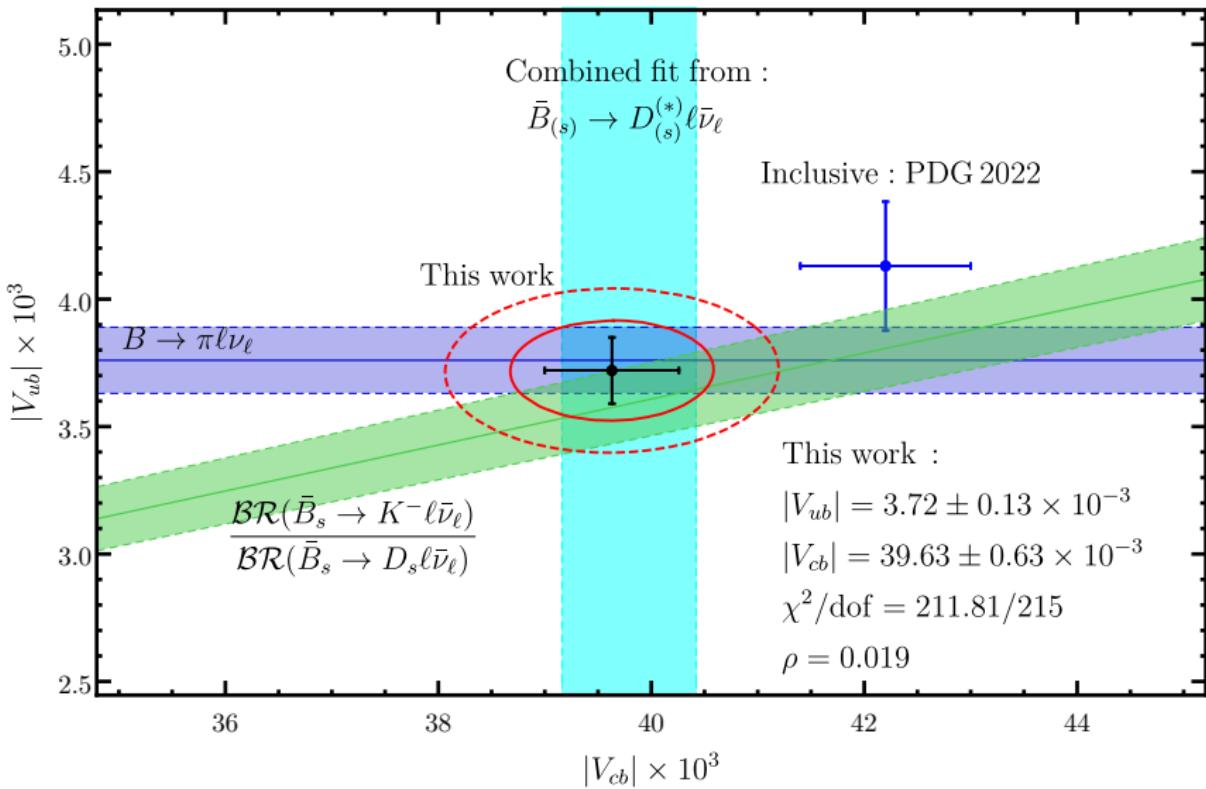


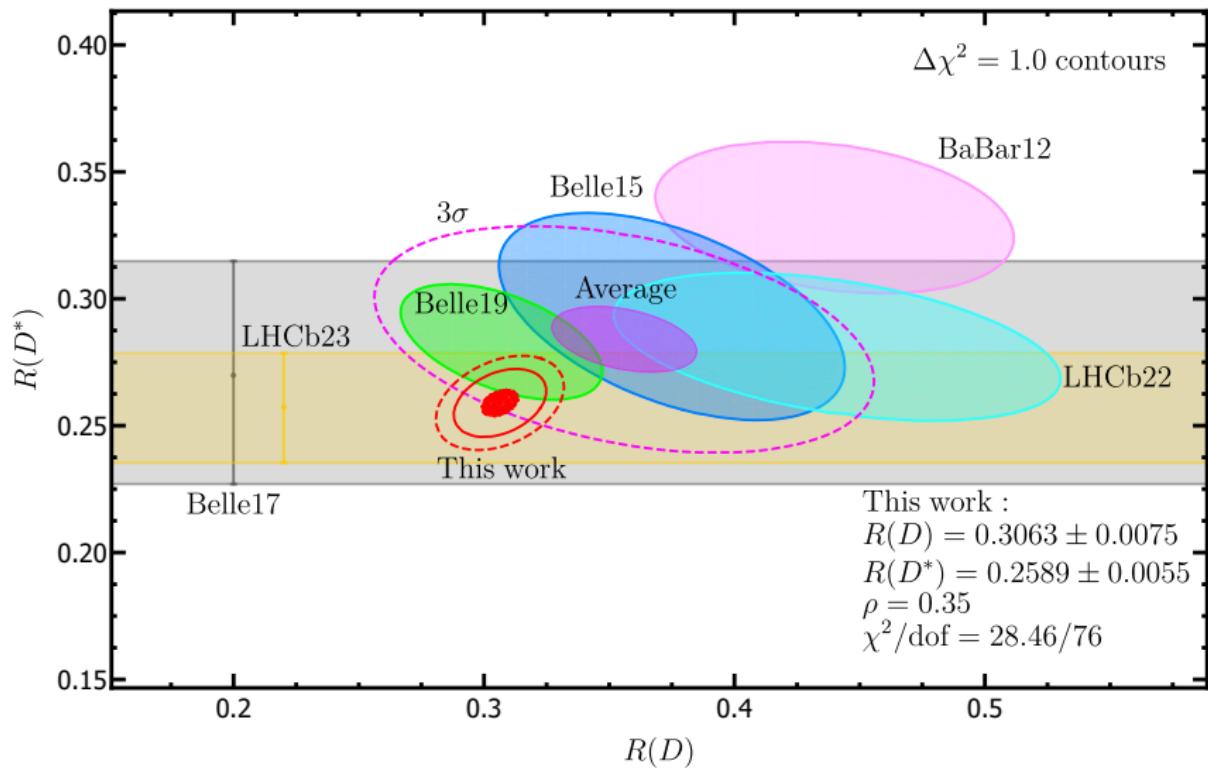


# SOME IMPROVED OBSERVABLES

# THREE SCENARIOS







# SUMMARY

- The complete SCET factorization formula for  $B_q \rightarrow D_q^*$ , including **NLL** and **NLP** (**NLP indispensable**).
- Combined fit for  $B_{(s)} \rightarrow D_{(s)}^{(*)}$ , improving the **precisions** of the form factors and some observables.
- $|V_{cb}|$  and  $\mathcal{R}(D^{(*)})$  predicted by the SM.
- Although decreased, the tension **still exists**.

**THANK YOU FOR YOUR ATTENTION!**