Flavor Frontier 2026

Iwate University 2/9/2026

V_{cb} determinations from exclusive decays

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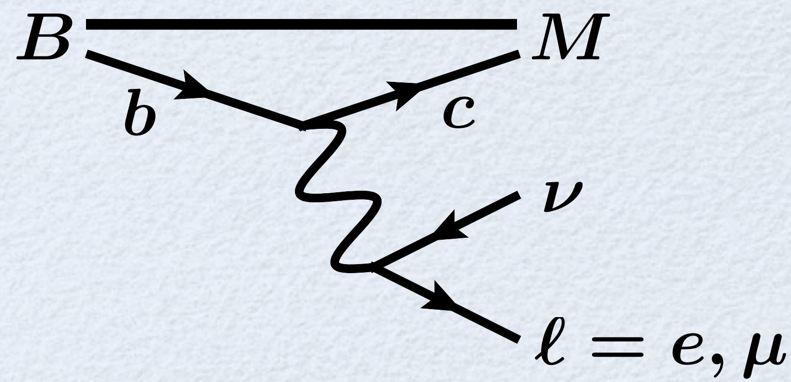
Status

V_{cb} has been measured from semi-leptonic decays

$$\frac{g}{\sqrt{2}} V_{cb}\, \bar{c}_L \gamma^\mu b_L W_\mu^+ + \text{h.c.}$$



Exclusive process: $M = D,\ D^*$

Inclusive process: $M = X_c$

Hadronic transitions need to be handled

$$\Gamma_{\text{excl}} \sim m_B^5 G_F^2 |V_{cb}|^2 \times (\text{Form Factor})$$

✓ Today's focus

$$\Gamma_{\text{incl}} \sim m_b^5 G_F^2 |V_{cb}|^2 \times (\text{OPE})$$

PDG average: $|V_{cb}| = \begin{cases} (39.5 \pm 0.5) \times 10^{-3} & (\text{exclusive}) \\ (42.2 \pm 0.5) \times 10^{-3} & (\text{inclusive}) \end{cases}$ ↕ "V_{cb} puzzle"

Form Factors

$$\langle D|\bar{c}\gamma^\nu b|B\rangle = \left[(p_B+p_D)^\nu - \frac{m_B^2-m_D^2}{q^2}q^\nu\right] f_+(q^2) + \frac{m_B^2-m_D^2}{q^2}q^\nu\, f_0(q^2)$$

$$\langle D^*|\bar{c}\gamma^\mu b|B\rangle = i\frac{2V(q^2)}{m_B+m_{D^*}}\varepsilon^{\mu\nu\rho\sigma}\epsilon^*_\nu\,(p_B)_\rho\,(p_{D^*})_\sigma$$

$$\langle D^*|\bar{c}\gamma^\mu\gamma^5 b|B\rangle = (m_B+m_{D^*})\epsilon^{*\mu}A_1(q^2) - \frac{(\epsilon^*\cdot q)}{m_B+m_{D^*}}(p_B+p_{D^*})^\mu A_2(q^2)$$
$$-\frac{2m_{D^*}}{q^2}(\epsilon^*\cdot q)q^\mu A_3(q^2)$$

SM contains 6 unknown functions with respect to q^2

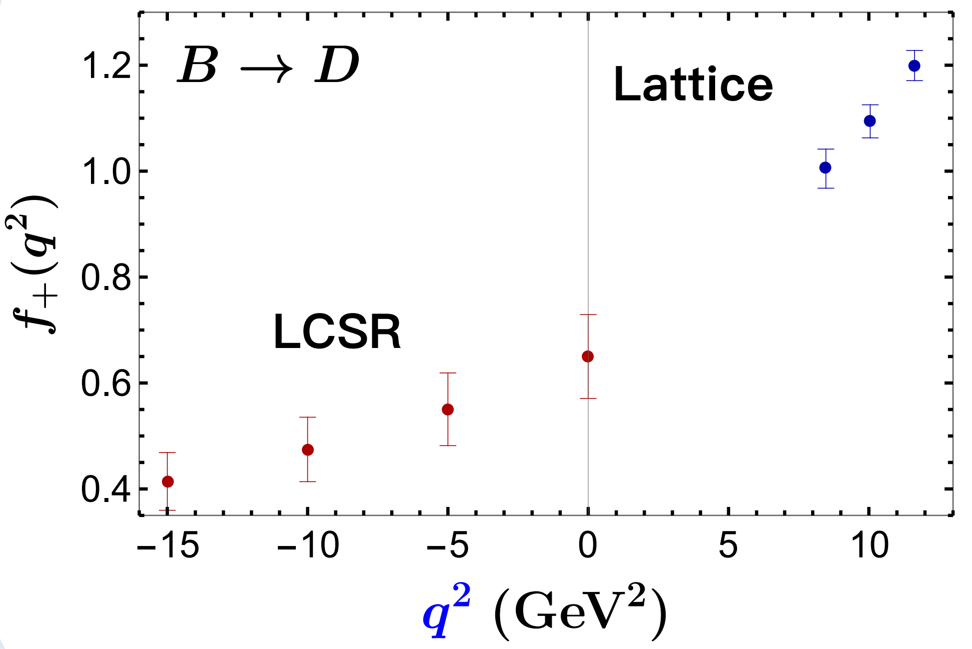
What we need:

<u>Evaluations</u> / <u>Measurements</u> / <u>Parameterizations & Fits</u>

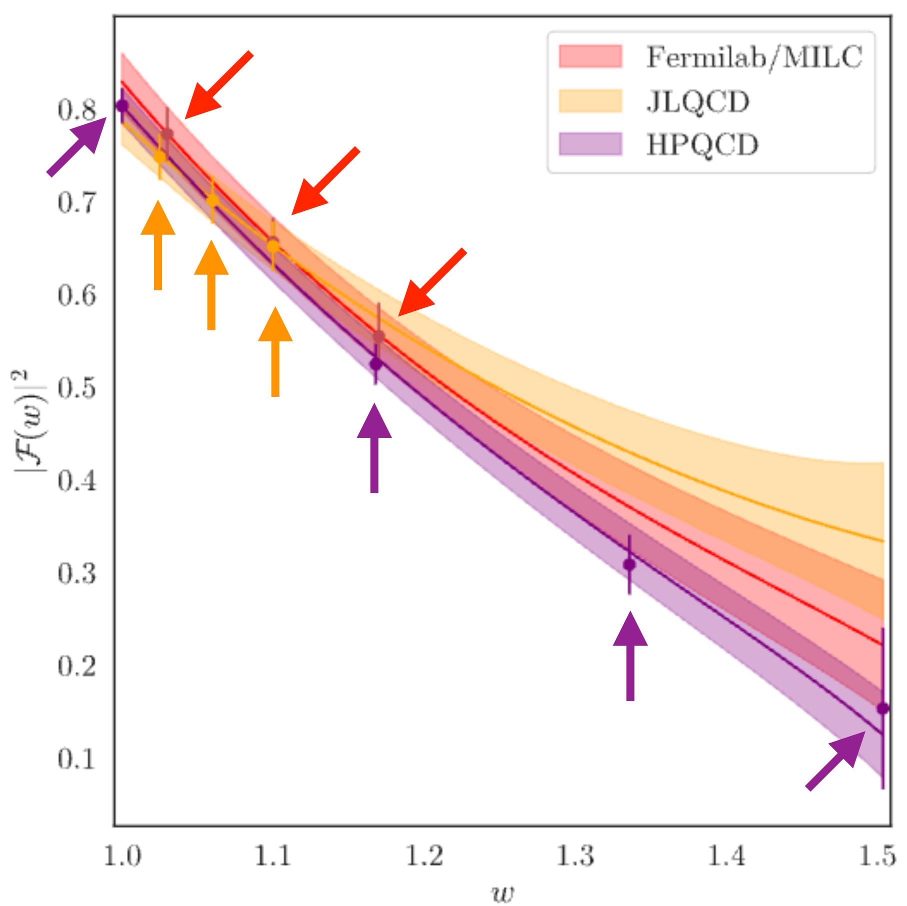
Evaluations

Lattice: $B \to D^{(*)}$ transition (near) zero-recoil $q^2 \sim (m_B - m_{D^{(*)}})^2$

LCSR: $(B, D^{(*)})$ production $q^2 < 0$



Recent evaluations $B \to D^*$



$$q^2 = m_B^2 + m_{D^{(*)}}^2 - 2 m_B m_{D^{(*)}}\, w$$

zero-recoil: $w \sim 1$

Measurements

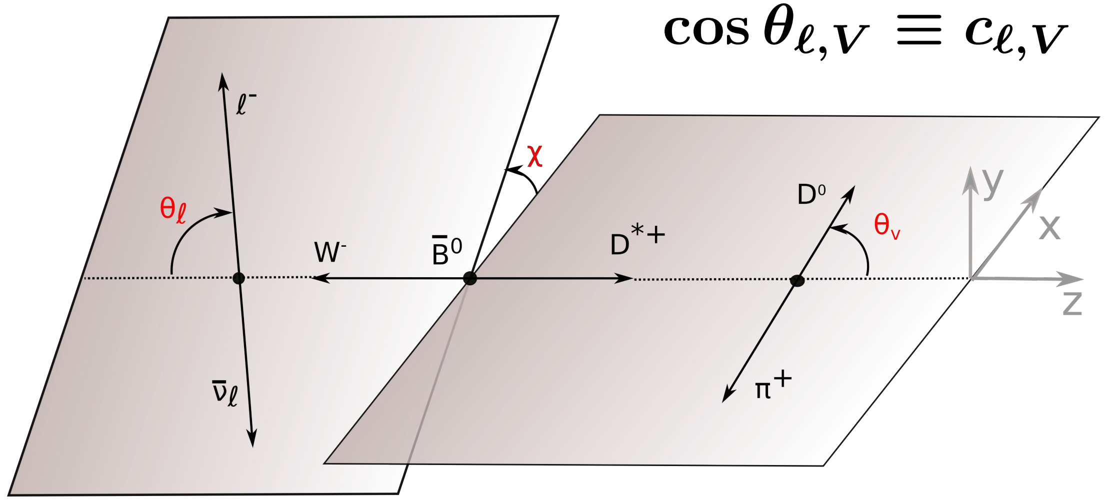
Decay Distribution: $$\frac{d\Gamma(B\to D\ell\nu)}{dq^2} = |V_{cb}|^2\,\hat{\Gamma}(q^2; f_+(q^2))$$

Recent measurement: Belle 2015, BelleII 2025

Angular obs: $$\frac{d\Gamma(B\to D^{*}(\to D\pi)\ell\nu)}{dq^2\,dc_\ell\,dc_V\,d\chi} = |V_{cb}|^2\,H(q^2; \mathrm{FF}(q^2))\,J(c_\ell, c_V, \chi)$$

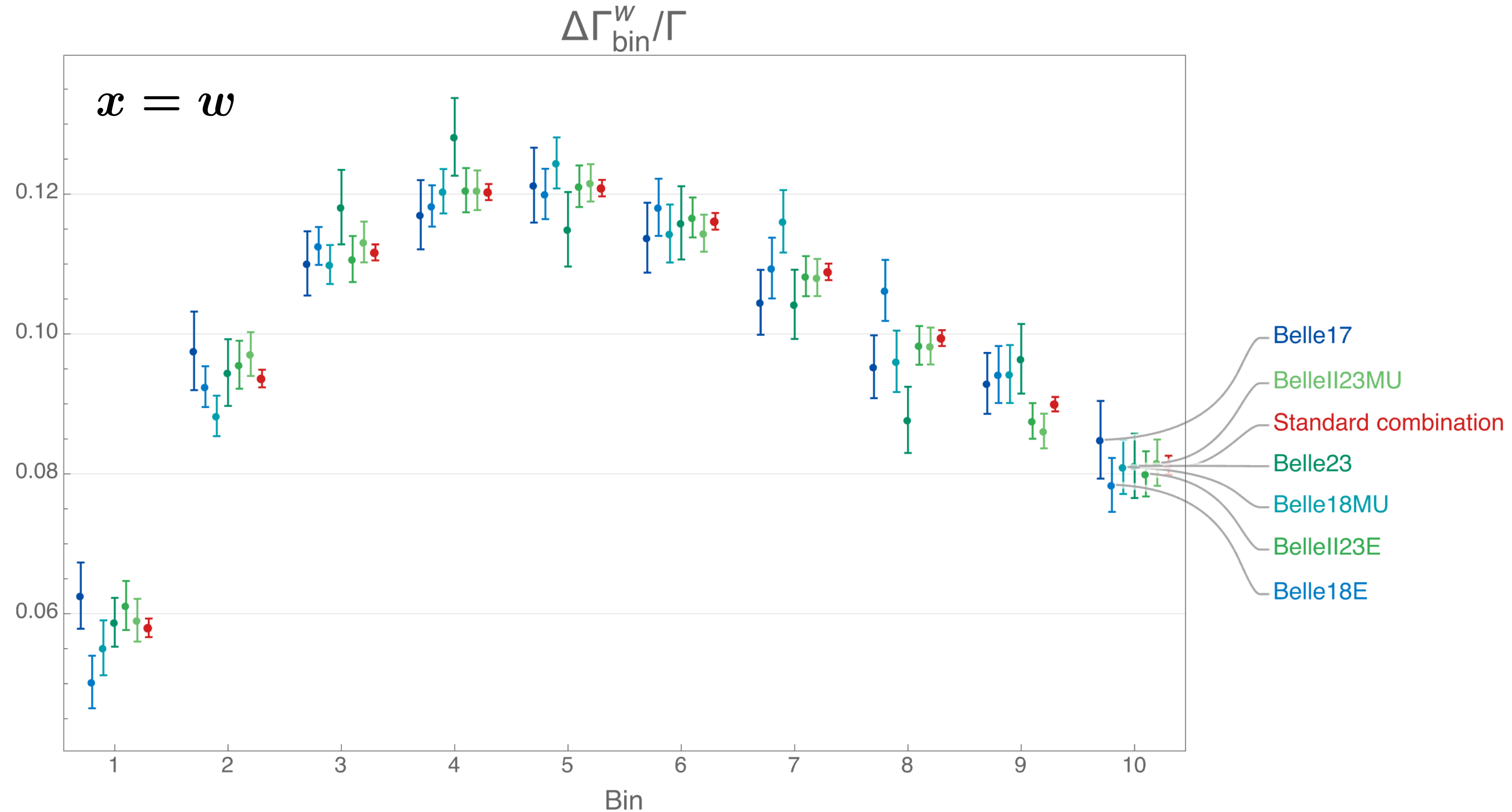
Recent measurements: Belle 2017, 2018, 2023, BelleII 2023

$$\cos\theta_{\ell,V} \equiv c_{\ell,V}$$



Measurements

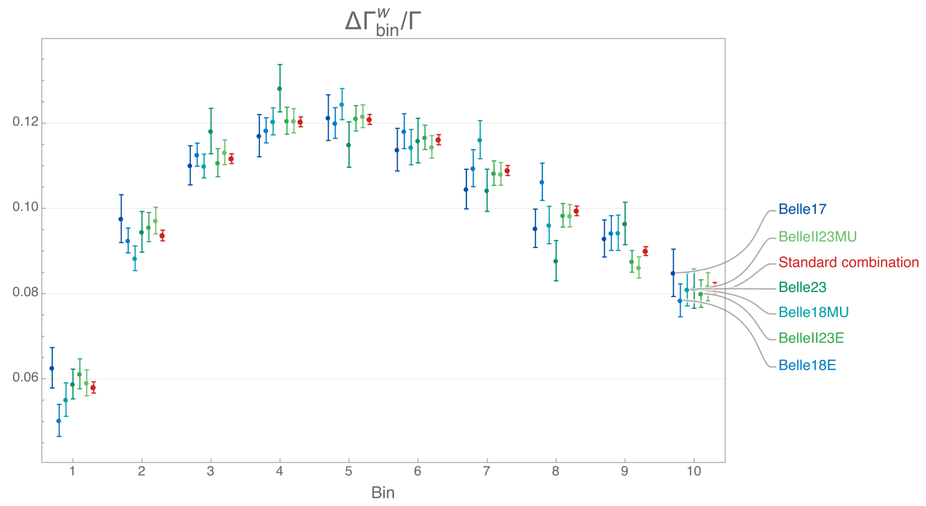
$$\Delta\Gamma^x_n = \int_{n\text{-bin}} \frac{d\Gamma(B \to D^*\ell\nu)}{dx}dx \quad \text{for} \quad x = \{w, \cos\theta_\ell, \cos\theta_V, \chi\}$$



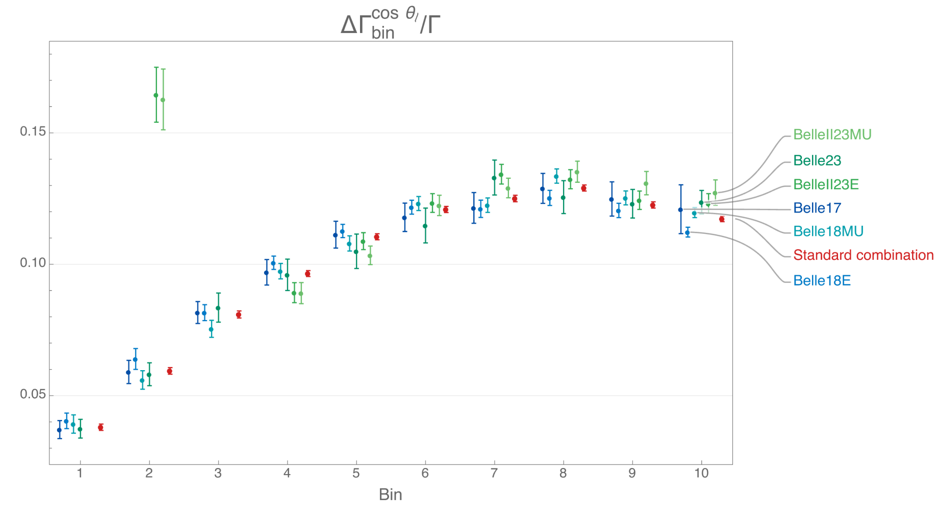
Combined average

Notice: these 4 data are statistically NOT independent

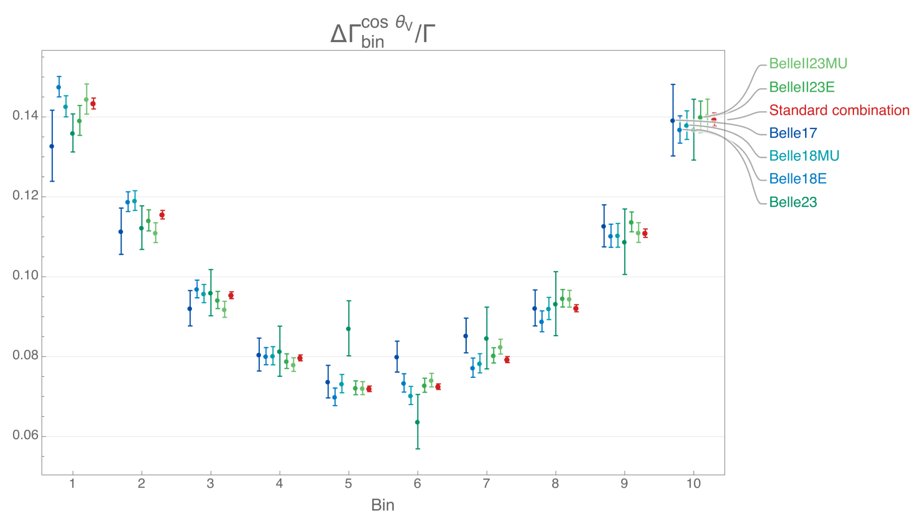
$$\Delta\Gamma_n^{w} = \int_{n\text{-bin}} \frac{d\Gamma(B \to D^*\ell\nu)}{dw}\, dw$$



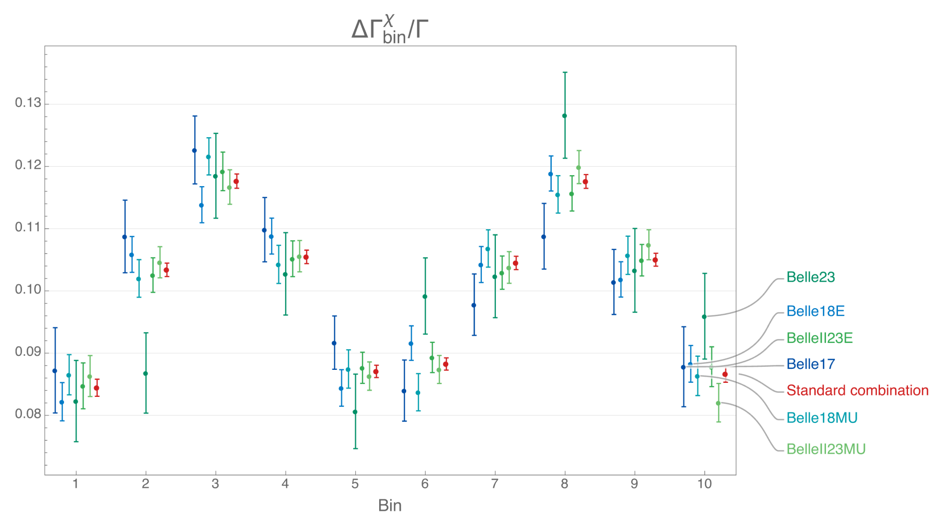
$$\Delta\Gamma_n^{\cos\theta_\ell} = \int_{n\text{-bin}} \frac{d\Gamma(B \to D^*\ell\nu)}{d\cos\theta_\ell}\, d\cos\theta_\ell$$



$$\Delta\Gamma_n^{\cos\theta_V} = \int_{n\text{-bin}} \frac{d\Gamma(B \to D^*\ell\nu)}{d\cos\theta_V}\, d\cos\theta_V$$



$$\Delta\Gamma_n^{\chi} = \int_{n\text{-bin}} \frac{d\Gamma(B \to D^*\ell\nu)}{d\chi}\, d\chi$$



Parameterizations

Exact q^2 (or w) shape is unknown → Need parameterization

i) All FFs are independent

Boyd, Grinstein, Lebed (1997)

BGL: $$F(w) \equiv \frac{1}{P_F(z)\phi_F(z)} \sum_{n=0}^{N_F} a_n^F z^n$$

— B→D and B→D* are independent subjects

— truncation order N_F is also undetermined → Check dependence

ii) All FFs are related

Jung, Straub (2018), Bordone, Jung, Dyk (2019)

HQET: $$F(w) = F_0(\xi(w)) + \frac{\Lambda}{m_Q} F_1(\chi_1(w), \chi_2(w), \chi_3(w)) + \left(\frac{\Lambda}{m_Q}\right)^2 F_2(\ell_1(w), \cdot$$

— described by "Heavy Quark Expansion"

— leading to common functions. We parameterize them.

$$\xi(w) \equiv \sum_{n=0}^{N_{\rm LO}} b_n^{\xi} (w-1)^n, \quad \chi(w) \equiv \sum_{n=0}^{N_{\rm NLO}} b_n^{\chi} (w-1)^n, \quad \ell(w) \equiv \sum_{n=0}^{N_{\rm NNLO}} b_n^{\ell} (w-1)^n$$

Our Study

$|V_{cb}|$ determination (our study)

1. Fit results in different FF parameterizations
2. Fit accuracy
3. New Physics effect
4. + α

Available data

$|V_{cb}|$ + FF (+NP) fits to available datasets

Lattice/LCSR	
Fermi-MILC 2014 (D^*)	$w = 1$ (zero-recoil)
Fermi-MILC 2015 (D)	$w = 1.00,\ 1.08,\ 1.16$
Fermi-MILC 2021 (D^*)	$w = 1.03,\ 1.10,\ 1.17$
HPQCD 2023 (D^*)	$q^2 = i \times q^2_{max}/3,\ \ i = 0,\ 1,\ 2,\ 3$
JLQCD 2023 (D^*)	$w = 1.025,\ 1.06,\ 1.10$
LCSR 2018 $(D^{(*)})$	$q^2/\mathrm{GeV}^2 = 0,\ -5,\ -10,\ -15$
LCSR 2023 $(D^{(*)})$	$q^2/\mathrm{GeV}^2 = 0,\ \pm1,\ \pm2,\ \pm3$

Distributions/Br	
Belle 2015 (D)	w distribution, 10 bins
Belle 2017 (D^*)	$(w, \theta_\ell, \theta_V, \chi)$ distributions, 40 bins
Belle 2018 (D^*)	$(w, \theta_\ell, \theta_V, \chi)$ distributions, 40 / 40 bins
Belle II 2023 (D^*)	$(w, \theta_\ell, \theta_V, \chi)$ distributions, 40 /40 bins
Belle 2023 (D^*)	$(w, \theta_\ell, \theta_V, \chi)$ distributions, 40 bins
Belle II 2025 (D^*)	w distribution, 10 bins
PDG 2025	Branching ratios

Fit scenarios

(A) fits to raw distribution data with one of $x = \{w, \cos\theta_\ell, \cos\theta_V, \chi\}$

$$\chi^2_{\rm all} = \chi^2(\text{Lattice,LCSR}; \mathbf{FF}) + \chi^2(\text{Br}; \mathbf{FF}, |V_{cb}|) + \chi^2(\Delta\Gamma^x_n; \mathbf{FF}, |V_{cb}|)$$

→ Four fit scenarios: (A, w), $(A, \cos\theta_\ell)$, $(A, \cos\theta_\ell)$, (A, χ)

(B) fits to normalized distribution data with all of $x = \{w, \cos\theta_\ell, \cos\theta_V, \chi\}$

$$\chi^2_{\rm all} = \chi^2(\text{Lattice,LCSR}; \mathbf{FF}) + \chi^2(\text{Br}; \mathbf{FF}, |V_{cb}|) + \chi^2(\Delta\Gamma^x_n/\Gamma; \mathbf{FF})$$

→ V_{cb} is determined solely from $\text{Br}(B \to D\ell\nu)$ and $\text{Br}(B \to D^*\ell\nu)$

→ Statistically unfair, but adopted for PDG average

FF parameterizations (reminder)

$$F = \begin{cases} f_+,\ f_0 \quad (B \to D) \\ f,\ \mathcal{F}_1,\ \mathcal{F}_2,\ g \quad (B \to D^*) \end{cases}$$

↕ related (HQET) / independent (BGL)

↔ related (HQET) / independent (BGL)

$|V_{cb}|$ fit results

Fit scenario	$\lvert V_{cb}\rvert$ fit result ($\times 10^3$)					
	BSZ		**BGL**		**HQET**	
	$N_F = 1$	$N_F = 2$	$N_F = 1$	$N_F = 2$	$(2/1/0)$	$(3/2/1)$
(A, w)	39.3 ± 0.4	39.6 ± 0.4	40.0 ± 0.4	39.6 ± 0.4	38.5 ± 0.3	38.2 ± 0.3
$(\mathrm{A}, \cos\theta_\ell)$	39.1 ± 0.4	39.8 ± 0.4	40.1 ± 0.4	39.9 ± 0.4	37.2 ± 0.3	37.5 ± 0.3
$(\mathrm{A}, \cos\theta_V)$	39.3 ± 0.4	39.9 ± 0.4	40.2 ± 0.4	40.0 ± 0.4	37.8 ± 0.3	38.1 ± 0.4
(A, χ)	39.9 ± 0.4	40.7 ± 0.4	41.0 ± 0.4	40.7 ± 0.5	39.0 ± 0.4	39.2 ± 0.4
$(\mathrm{B}) + \mathcal{B}(B^+ \to \bar{D}^0 \ell^+ \nu)$	37.8 ± 0.7	39.0 ± 0.8	39.2 ± 0.8	38.9 ± 0.8	39.4 ± 0.8	37.8 ± 0.8
$(\mathrm{B}) + \mathcal{B}(B^+ \to \bar{D}^{*0} \ell^+ \nu)$	40.0 ± 0.5	39.8 ± 0.6	40.3 ± 0.5	39.8 ± 0.6	37.9 ± 0.5	38.6 ± 0.5
$(\mathrm{B}) + \text{combined}$	39.2 ± 0.4	$\mathbf{39.5 \pm 0.5}$	40.0 ± 0.4	$\mathbf{39.5 \pm 0.5}$	38.3 ± 0.6	38.3 ± 0.7

- BGL/BSZ (N_F=2) reproduce the PDG average in fit scenario (B)
- BGL/BSZ give consistent results except for (A, χ)
- HQET fit lowers Vcb → bad news for comparing with inclusive Vcb

Fit accuracy

Fit scenario	$\chi^2_{\text{best}}/\text{bin}$ for Distribution / BrRatio / Lattice			
	BGL		HQET	
	$N_F = 1$	$N_F = 2$	(2/1/0)	(3/2/1)
(A, w)	0.5 / 0.6 / 0.8	0.3 / 0.4 / $\boxed{1.2}$	0.6 / 0.1 / $\boxed{2.0}$	0.5 / 0.5 / $\boxed{1.4}$
(A, $\cos\theta_\ell$)	0.3 / 0.7 / 1.3	0.5 / 0.6 / $\boxed{1.7}$	0.5 / 1.0 / $\boxed{2.7}$	0.6 / 0.1 / $\boxed{1.5}$
(A, $\cos\theta_V$)	0.3 / 0.7 / 1.1	0.6 / 0.7 / $\boxed{1.5}$	0.4 / 0.6 / $\boxed{2.3}$	0.6 / 0.4 / $\boxed{1.3}$
(A, χ)	$\boxed{3.1}$ / 1.6 / 0.7	$\boxed{3.2}$ / 1.3 / $\boxed{1.0}$	1.6 / 0.2 / $\boxed{2.0}$	$\boxed{2.0}$ / 1.2 / $\boxed{1.1}$
(B)	0.4 / $\boxed{1.6}$ / 0.9	0.5 / $\boxed{1.1}$ / $\boxed{1.3}$	0.6 / $\boxed{3.1}$ / 1.6	0.5 / 0.9 / $\boxed{1.4}$

- Fits with fewer parameters (N_F=1, 2/1/0) tend to be poor
- Fits in the (A, χ) scenario are poor for the Distribution data
- Fits in scenario (B) are poor/marginal for the branching ratios
- Fits to the Lattice data are marginal at best → more details

Fit accuracy to Lattice

Fit scenario	$\chi^2_{\rm best}$/bin for MILC15 / MILC21 / JLQCD23 / HPQCD23			
	BGL		HQET	
	$N_F = 1$	$N_F = 2$	(2/1/0)	(3/2/1)
(A, w)	0.8 / 2.2 / 1.0 / 0.3	0.8 / 3.4 / 1.4 / 0.3	2.8 / 3.4 / 2.0 / 0.6	0.8 / 3.0 / 1.2 / 0.6
(A, $\cos\theta_\ell$)	0.8 / 2.6 / 1.0 / 0.3	0.5 / 3.5 / 1.6 / 0.3	4.2 / 3.8 / 3.4 / 0.6	0.5 / 3.1 / 1.5 / 0.8
(A, $\cos\theta_V$)	0.5 / 2.3 / 0.9 / 0.3	0.7 / 3.6 / 1.6 / 0.3	4.8 / 3.5 / 2.3 / 0.7	0.8 / 3.4 / 0.8 / 0.7
(A, χ)	0.7 / 1.5 / 0.7 / 0.2	1.0 / 3.3 / 1.8 / 0.3	4.2 / 3.0 / 2.1 / 0.6	1.2 / 2.4 / 1.1 / 0.7
(B)	0.7 / 2.0 / 0.8 / 0.2	0.5 / 3.5 / 1.8 / 0.3	1.7 / 3.3 / 2.2 / 0.6	1.2 / 3.3 / 0.9 / 0.8

[Data numbers] MILC15: 6 bins / MILC21: 12 / JLQCD23: 12 / HPQCD23: 20

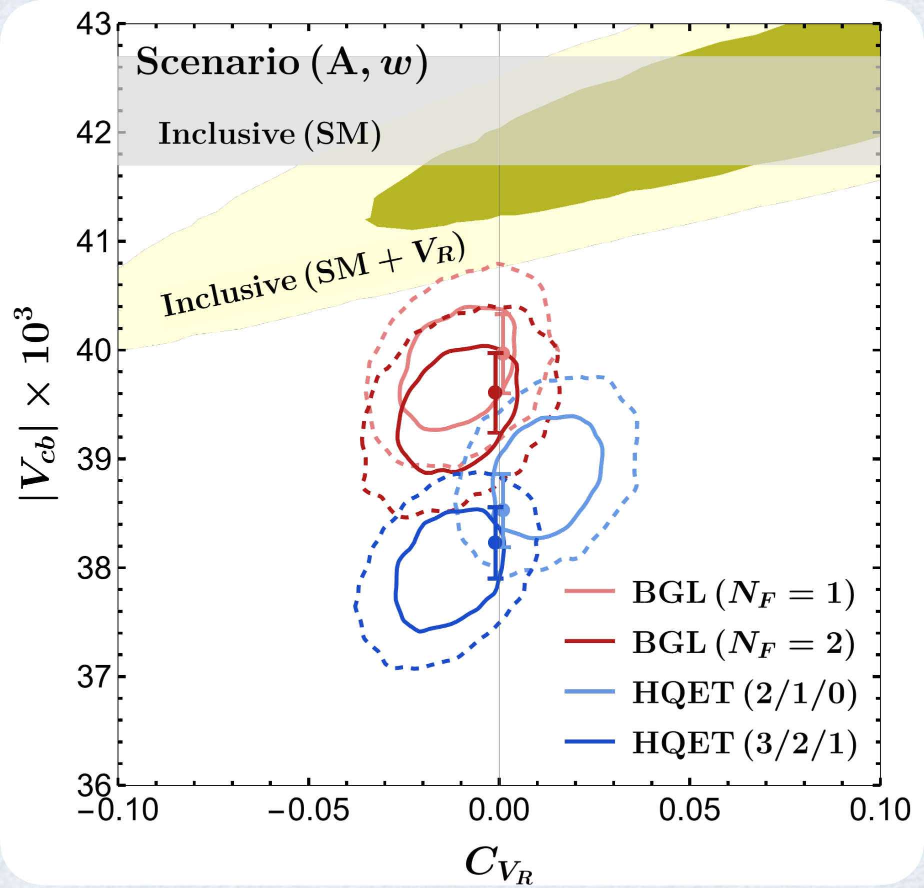
- Fits to MILC21 are very poor = inconsistent with other data
- Fits to JLQCD23 are always marginal
- Fits to HPQCD23 are good just due to larger errors

New Physics effect

Setup

$$\mathcal{H}_{\rm eff}^{b\to c\ell\nu} = \frac{4G_F}{\sqrt{2}} V_{cb}\Big[(\bar{c}\gamma^\mu P_L b)(\bar{\ell}\gamma_\mu P_L \nu_\ell) + C_{V_R}(\bar{c}\gamma^\mu P_R b)(\bar{\ell}\gamma_\mu P_L \nu_\ell) + C_{S_L}(\bar{c}P_L b)(\bar{\ell}P_L\nu_\ell) + C_{S_R}(\bar{c}P_R b)(\bar{\ell}P_L\nu_\ell) + C_T(\bar{c}\sigma^{\mu\nu}P_L b)(\bar{\ell}\sigma_{\mu\nu}P_L\nu_\ell)\Big]$$

Main result



SM + V_R fits:

- slightly prefers non-zero NP $(C_{V_R} \approx -0.02)$
- do not much improve the fit $(\Delta\chi^2 \approx 2)$
- still not consistent with inclusive V_{cb}

SM + S, T fits:

- show no interesting result (zero-consistent)

Summary

What we saw in $|V_{cb}|$ determination

1. Fit results in different FF parameterizations
2. Fit accuracy
3. New Physics effect

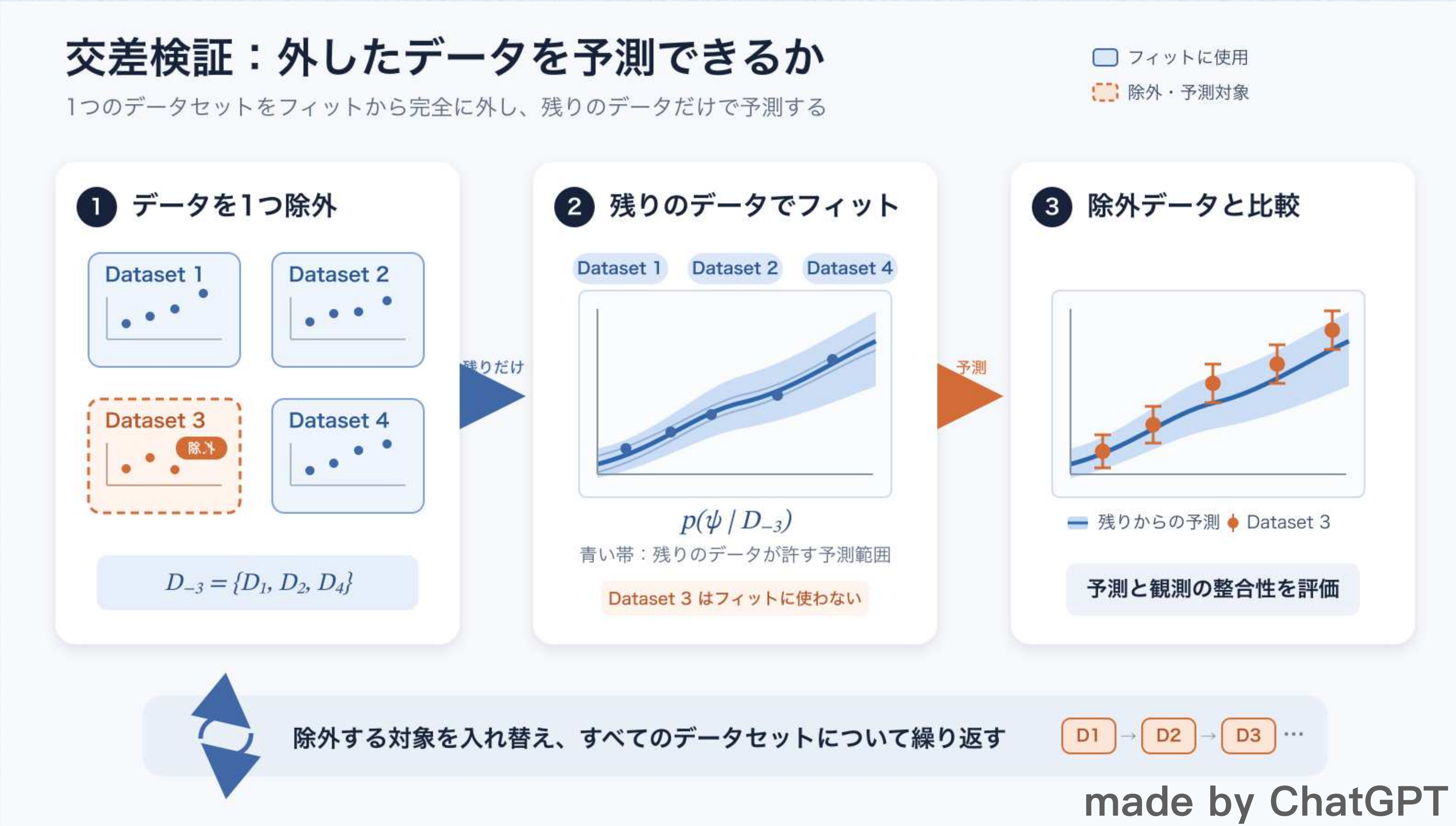
What we got

- BGL/BSZ (NF=2) reproduce the PDG average
- BGL/BSZ give consistent results almost among different fit scenarios
- HQET shows smaller Vcb

  → How should we think about the difference between BGL and HQET?

- Lattice MILC21 data are not consistent with the other datasets
- New Physics effects do not improve the fit
- New Physics effects do not reproduce the inclusive Vcb result

+ α: statistical tests



+ α: 交差検証 (BGL)

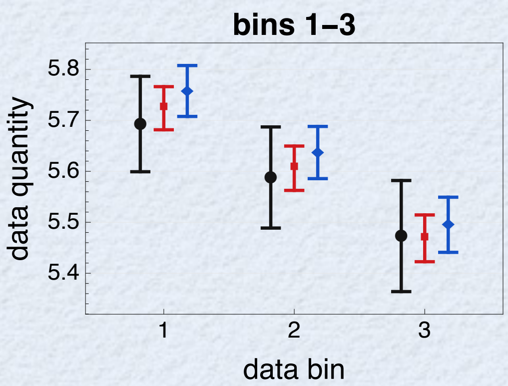
Work in progress...

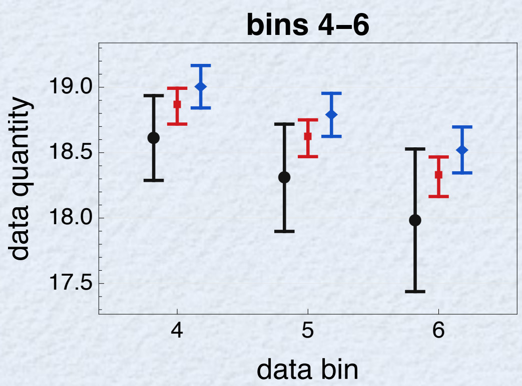
フィット除外データ	Predictive p-value	$\Delta\|V_{cb}\|$ $[10^{-3}]$
MILC21	3.96×10^{-10}	-0.264
JLQCD23	6.30×10^{-3}	-0.107
HPQCD23	0.9979	$+0.139$
LCSR18	0.5233	-0.052
LCSR23	2.33×10^{-17}	-0.415
$\Delta\Gamma^{w}_{\rm bin}/\Gamma$	7.65×10^{-3}	$+0.532$
$\Delta\Gamma^{\cos\theta_\ell}_{\rm bin}/\Gamma$	0.9642	$+0.005$
$\Delta\Gamma^{\cos\theta_V}_{\rm bin}/\Gamma$	0.9412	$+0.011$
$\Delta\Gamma^{\chi}_{\rm bin}/\Gamma$	0.9991	$+0.002$

← as expected (MILC21, JLQCD23)

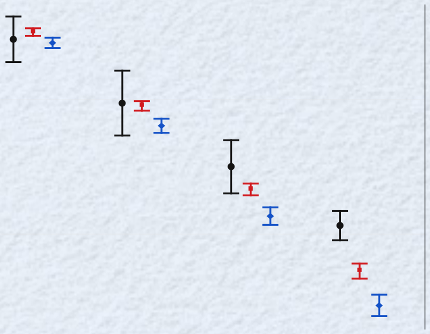
← unexpected ($\Delta\Gamma^{w}_{\rm bin}/\Gamma$)

JLQCD23 (data/fit/交差検証)





ΔΓw/Γ (data/fit/交差検証)



Backup

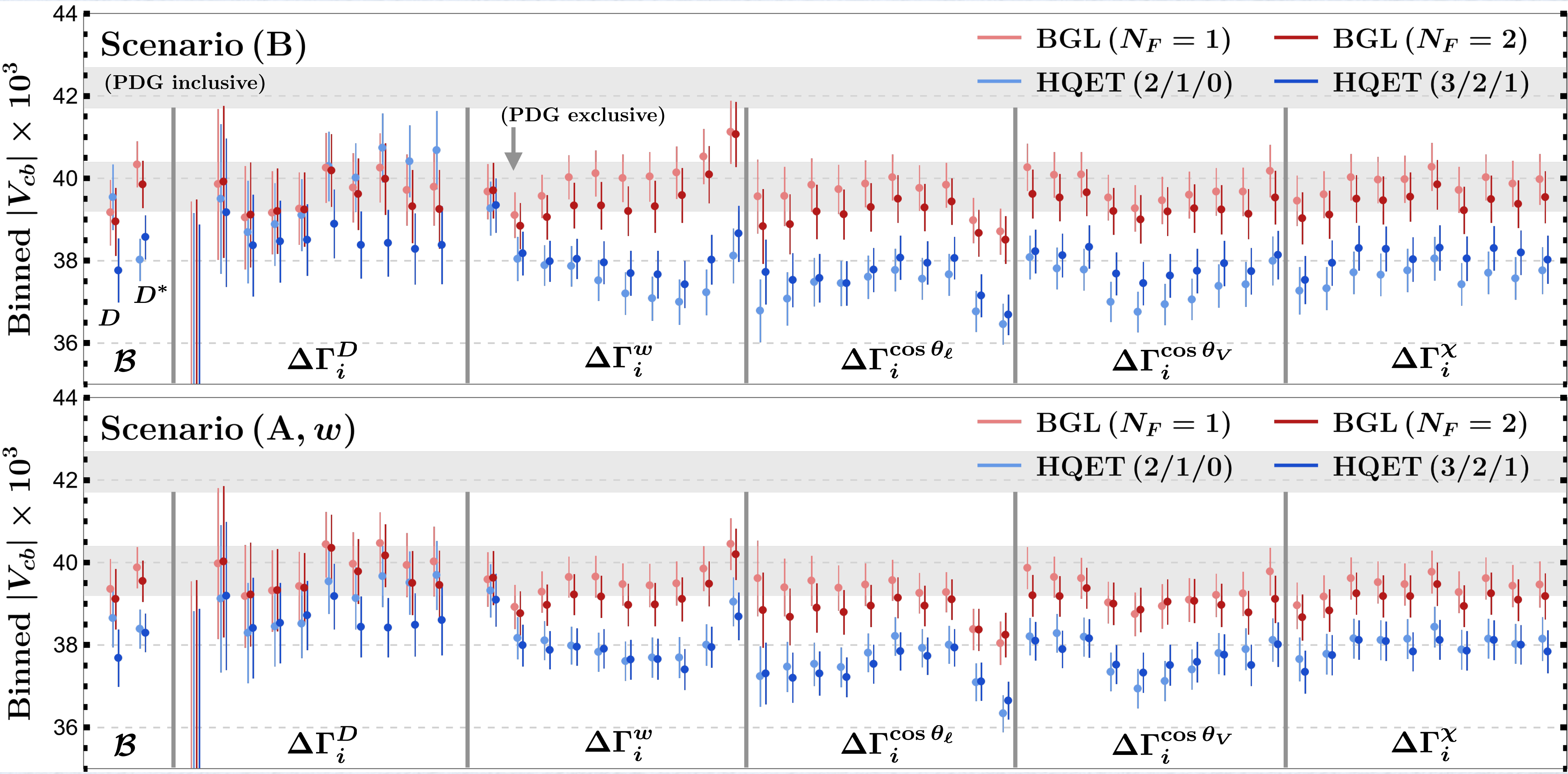
$$R_D^{\rm ave} = 0.358 \pm 0.024\,, \qquad R_{D^*}^{\rm ave} = 0.281 \pm 0.011\,,$$

$$R_D^{\rm SM\text{-}HFLAV} = 0.296 \pm 0.004\,, \qquad R_{D^*}^{\rm SM\text{-}HFLAV} = 0.254 \pm 0.005\,.$$

Fit scenario	**BGL** ($N_F = 1$)	**BGL** ($N_F = 2$)	**HQET** (2/1/0)	**HQET** (3/2/1)
		R_D		
(A, w)	0.296 ± 0.002	0.289 ± 0.002	0.297 ± 0.005	0.282 ± 0.004
(A, $\cos\theta_\ell$)	0.296 ± 0.002	0.289 ± 0.003	0.293 ± 0.005	0.282 ± 0.004
(A, $\cos\theta_V$)	0.296 ± 0.002	0.290 ± 0.003	0.296 ± 0.005	0.282 ± 0.004
(A, χ)	0.298 ± 0.002	0.291 ± 0.003	0.298 ± 0.005	0.285 ± 0.004
(B)	0.295 ± 0.003	0.288 ± 0.003	0.301 ± 0.006	0.285 ± 0.005
		R_{D^*}		
(A, w)	0.252 ± 0.001	0.252 ± 0.001	0.250 ± 0.001	0.250 ± 0.001
(A, $\cos\theta_\ell$)	0.254 ± 0.002	0.256 ± 0.002	0.243 ± 0.003	0.244 ± 0.006
(A, $\cos\theta_V$)	0.254 ± 0.002	0.256 ± 0.002	0.244 ± 0.004	0.247 ± 0.006
(A, χ)	0.262 ± 0.002	0.262 ± 0.002	0.253 ± 0.004	0.261 ± 0.007
(B)	0.254 ± 0.001	0.254 ± 0.001	0.248 ± 0.002	0.252 ± 0.002

$|V_{cb}|$ from the distribution data

$$\Delta\Gamma_n^x(\text{theory}) = \int_{x_n}^{x_{n+1}} \frac{d\Gamma}{dx} dx = |V_{cb}|^2 \times \hat{\Gamma}_n^x(\mathbf{FF}) \quad \Rightarrow \quad |V_{cb}|_n^x = \sqrt{\frac{\Delta\Gamma_n^x(\text{exp})}{\hat{\Gamma}_n^x(\mathbf{FF})}}$$



Parameterizations

Exact q^2 (or w) shape is unknown

Several parameterizations have been proposed

0. CLN

Caprini, Lellouch, Neubert (1997)

— **"Traditional" parameterization based on HQET**

— **Shape is approximated with only one parameter for all FFs**

$$f_+(w) = N_f \left[1 - 8\rho^2 z + (51\rho^2 - 10)z^2 - (252\rho^2 - 84)z^3\right], \quad z = \frac{\sqrt{w+1} - \sqrt{2}}{\sqrt{w+1} + \sqrt{2}}$$

Message from theory people

- **CLN does not take proper heavy quark expansion**
- **CLN approx. is too much simple (we have large data points)**
- **So, please do not use for your fit study**

1. BGL

Boyd, Grinstein, Lebed (1997)

— "General" parameterization with minimum requirement

— Each Form Factor involves independent parameters given N_F

$$F(w) \equiv \frac{1}{P_F(z)\phi_F(z)} \sum_{n=0}^{N_F} a_n^F z^n\,, \quad F = \begin{cases} f_+,\ f_0 & (B \to D) \\ f,\ \mathcal{F}_1,\ \mathcal{F}_2,\ g & (B \to D^*) \end{cases}$$

2. HQET

Jung, Straub (2018), Bordone, Jung, Dyk (2019)

— Parameterization based on "Heavy Quark Expansion"

— Form Factors are given with common functions (IW functions)

$$F(w) = F_0(\xi(w)) + \frac{\Lambda}{m_Q} F_1(\chi_1(w), \chi_2(w), \chi_3(w)) + \left(\frac{\Lambda}{m_Q}\right)^2 F_2(\ell_1(w), \cdots)$$

— Up to $1/m_b,\ 1/m_c,\ 1/m_c^2$ terms are sensitive $\quad (\Lambda/m_c)^2 \sim (\Lambda/m_b)^1$

— Parameterizations given for IW functions

$$\xi(w) \equiv \sum_{n=0}^{N_{\rm LO}} b_n^{\xi} z^n, \quad \chi(w) \equiv \sum_{n=0}^{N_{\rm NLO}} b_n^{\chi} z^n, \quad \ell(w) \equiv \sum_{n=0}^{N_{\rm NNLO}} b_n^{\ell} z^n$$

Fit study for HQET vs BGL

Setup

HQET: $(N_{\mathrm{LO}}/N_{\mathrm{NLO}}/N_{\mathrm{NNLO}}) = \begin{cases} (3/2/1) & \to \textbf{23 parameters!} \\ (2/1/0) & \to \textbf{13 parameters!} \end{cases}$

BGL: $N_F = \begin{cases} 2 \\ 1 \end{cases}$ for all F $\begin{matrix} \to \textbf{16 parameters!} \\ \to \textbf{11 parameters!} \end{matrix}$

Fit data: Lattice/LCSR → FF, Distributions/Br → FF & |Vcb|

Lattice/LCSR	
Fermi-MILC 2014 (D^*)	$w = 1$ (zero-recoil)
Fermi-MILC 2015 (D)	$w = 1.00,\ 1.08,\ 1.16$
Fermi-MILC 2021 (D^*)	$w = 1.03,\ 1.10,\ 1.17$
HPQCD 2023 (D^*)	$q^2 = i \times q^2_{max}/3,\ i = 0,\ 1,\ 2,\ 3$
JLQCD 2023 (D^*)	$w = 1.025,\ 1.06,\ 1.10$
LCSR 2018 $(D^{(*)})$	$q^2/\mathrm{GeV}^2 = 0,\ -5,\ -10,\ -15$
LCSR 2023 $(D^{(*)})$	$q^2/\mathrm{GeV}^2 = 0,\ \pm1,\ \pm2,\ \pm3$

Distributions/Br	
Belle 2015 (D)	w distribution, 10 bins
Belle 2017 (D^*)	$(w, \theta_\ell, \theta_V, \chi)$ distributions, 40 bins
Belle 2018 (D^*)	$(w, \theta_\ell, \theta_V, \chi)$ distributions, 40 / 40 bins
Belle II 2023 (D^*)	$(w, \theta_\ell, \theta_V, \chi)$ distributions, 40 /40 bins
Belle 2023 (D^*)	$(w, \theta_\ell, \theta_V, \chi)$ distributions, 40 bins
Belle II 2025 (D^*)	w distribution, 10 bins
PDG $(D,\ D^*)$	

New Physics effect

Setup

$$\mathcal{H}_{\rm eff}^{b\to c\ell\nu} = \frac{4G_F}{\sqrt{2}} V_{cb} \Big[(\bar{c}\gamma^\mu P_L b)(\bar{\ell}\gamma_\mu P_L \nu_\ell) + C_{V_R}(\bar{c}\gamma^\mu P_R b)(\bar{\ell}\gamma_\mu P_L \nu_\ell) + C_{S_L}(\bar{c}P_L b)(\bar{\ell}P_L\nu_\ell) + C_{S_R}(\bar{c}P_R b)(\bar{\ell}P_L\nu_\ell) + C_T(\bar{c}\sigma^{\mu\nu}P_L b)(\bar{\ell}\sigma_{\mu\nu}P_L\nu_\ell) \Big]$$

Form Factors

SM scalar FFs

Scalar: $\langle D|\bar{c}b|B\rangle = \frac{m_B^2 - m_D^2}{m_b - m_c} f_0(q^2)\,, \quad \langle D^*|\bar{c}\gamma^5 b|B\rangle = \frac{2m_{D^*}}{m_b + m_c}(\epsilon^* \cdot q) A_0(q^2)\,,$

Tensor: $\langle D|\bar{c}\sigma^{\mu\nu}b|B\rangle = \frac{-2i}{m_B + m_D}(p_B^\mu p_D^\nu - p_B^\nu p_D^\mu) f_T(q^2)\,,$

$\langle D^*|\bar{c}\sigma^{\mu\nu}b|B\rangle \supset T_1(q^2)\,, T_2(q^2)\,, T_2(q^2)$

Parameterization

BGL: additional independent FFs (HQPCD23, LCSR18, dist. available)

HQET: common IW functions with SM