MITP July 2026

Flavourful Opportunities in Semileptonic B Decays: Connecting Theory and Experiment

Experimental status of $b\to c\ell\nu$ decays

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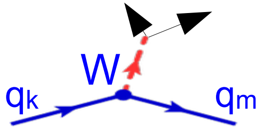
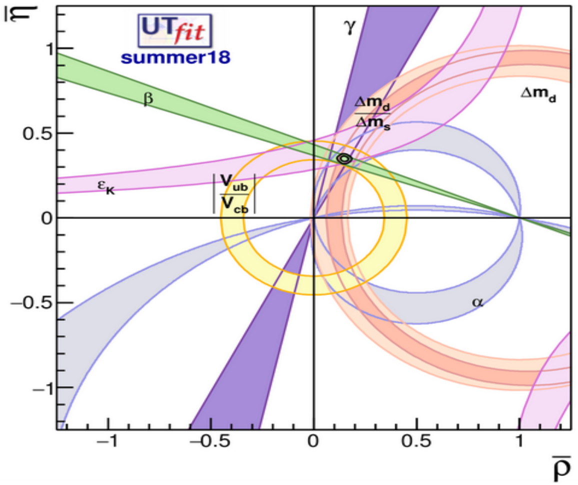
Why semileptonic b→cℓν decays ?



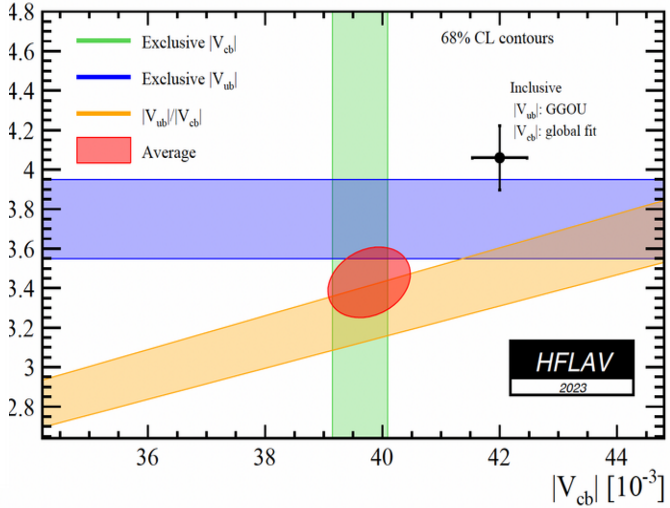
$\left| \quad \right|^2 \sim |V_{km}|^2$

$$\frac{\Gamma(B \to D^{(*)}\tau\nu_\tau)}{\Gamma(B \to D^{(*)}\ell\nu_\ell)}$$

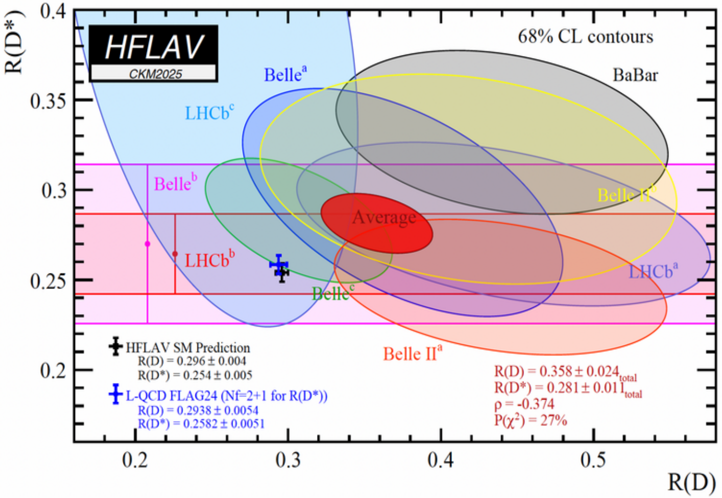


$|V_{xb}|$ provide crucial inputs for indirect search of New Physics

FCNC $\propto |V_{tb}V_{ts}|^2 \approx |V_{cb}|^2[1 + O(\lambda^2)]$

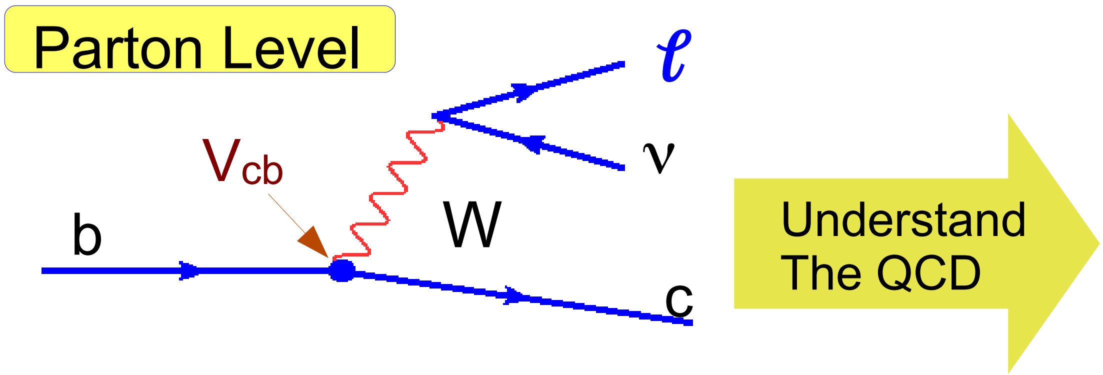


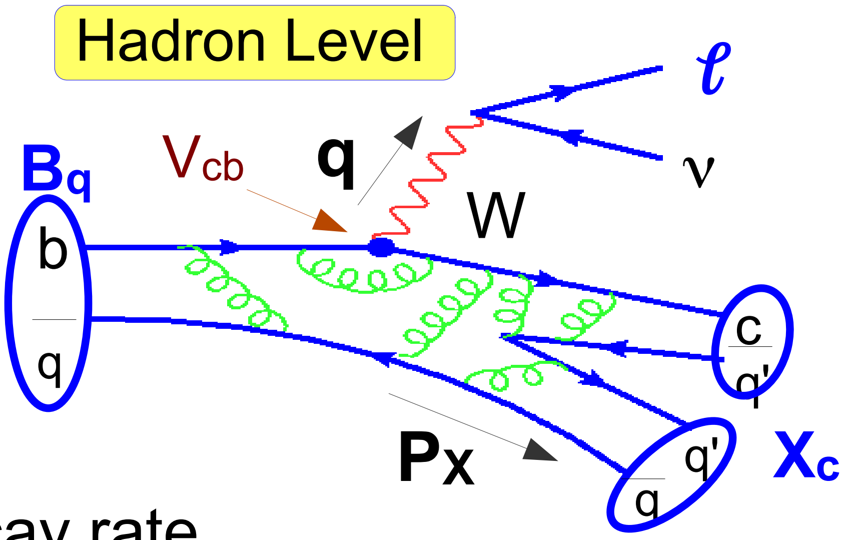
$|V_{ub}|$ and $|V_{cb}|$ discrepancies between different determinations: 2-3σ effect



The b → c form factors are crucial to SM predictions of R and other observables

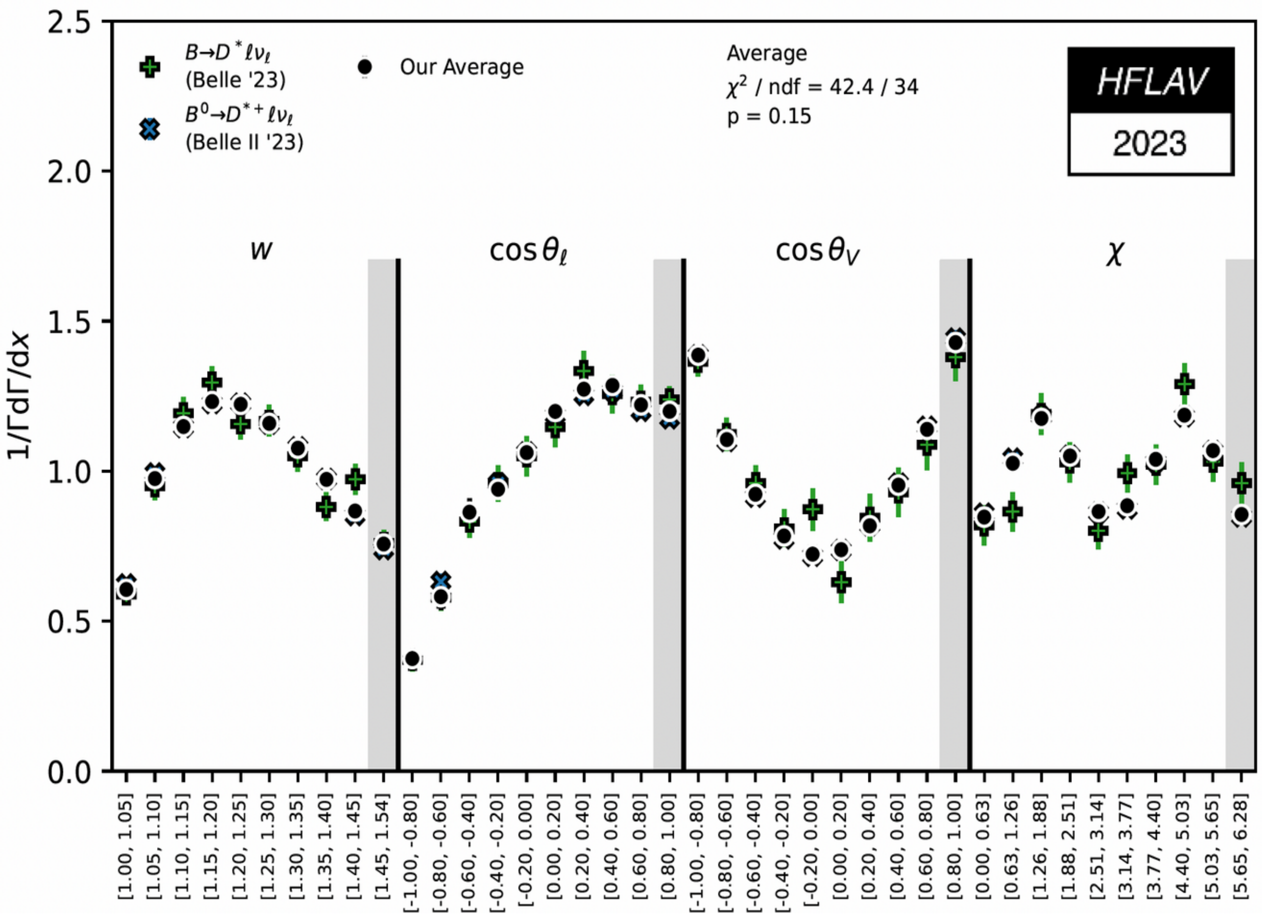
Semileptonic $b \to c \ell \nu$ decays



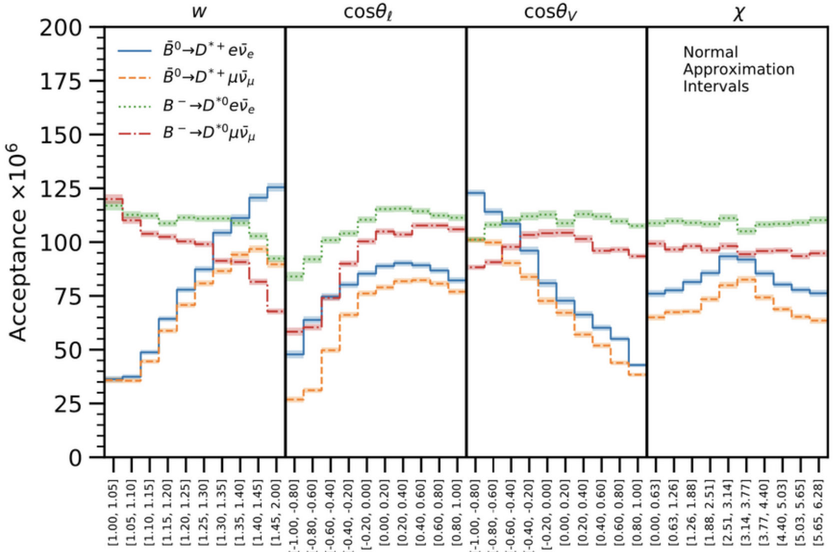


- Inclusive decays $B \to X_c \ell \nu$:
  - QCD corrections to parton level decay rate
  - Operator Production Expansion in α_s and Λ/m_b
- Exclusive decays $B \to D/D^* \ell \nu$:
  - QCD correction parameterized in the Form Factors
  - Lattice-QCD, LCSR

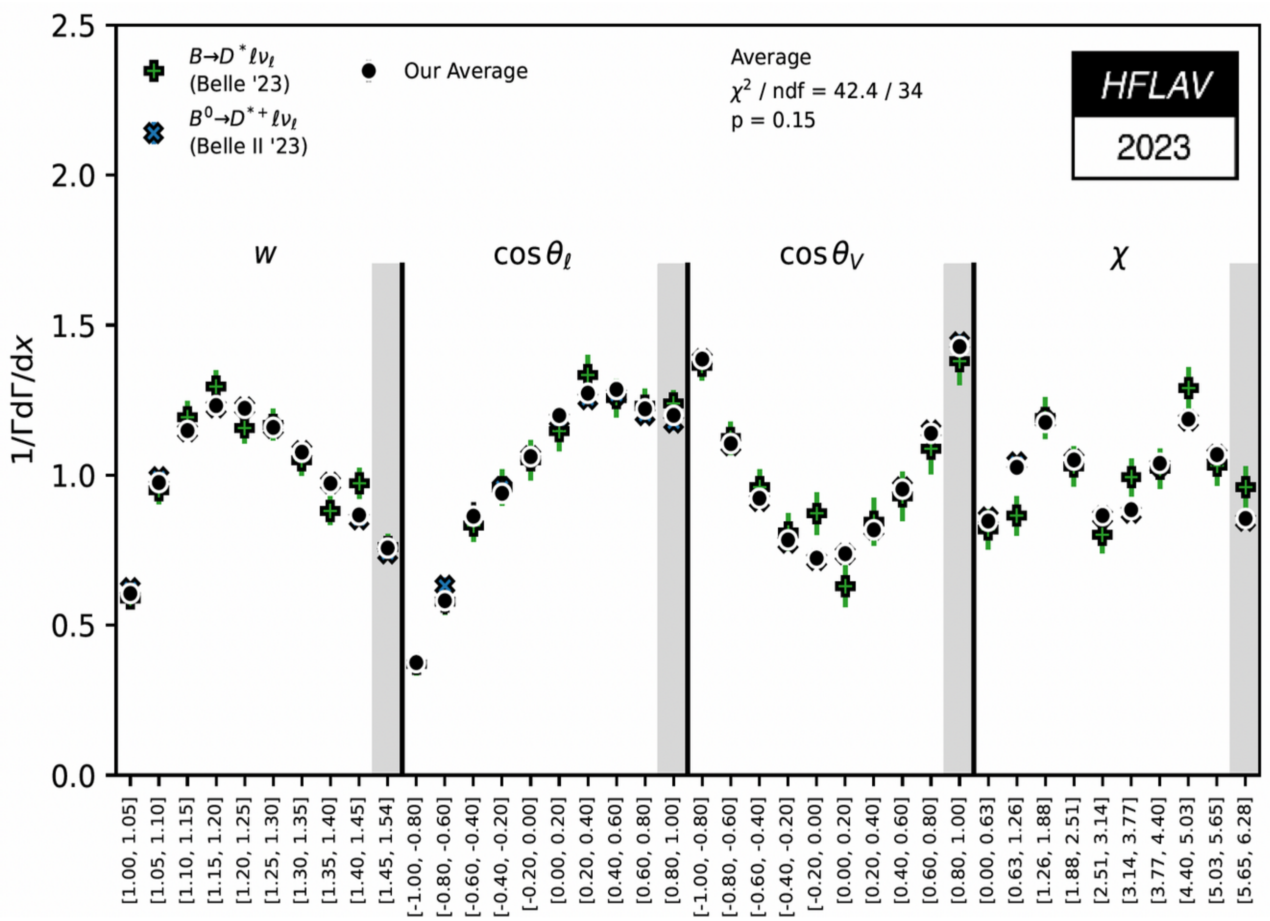
B→D*ℓν decays



Belle 23:
Hadronic tag
only projections to differential distribution



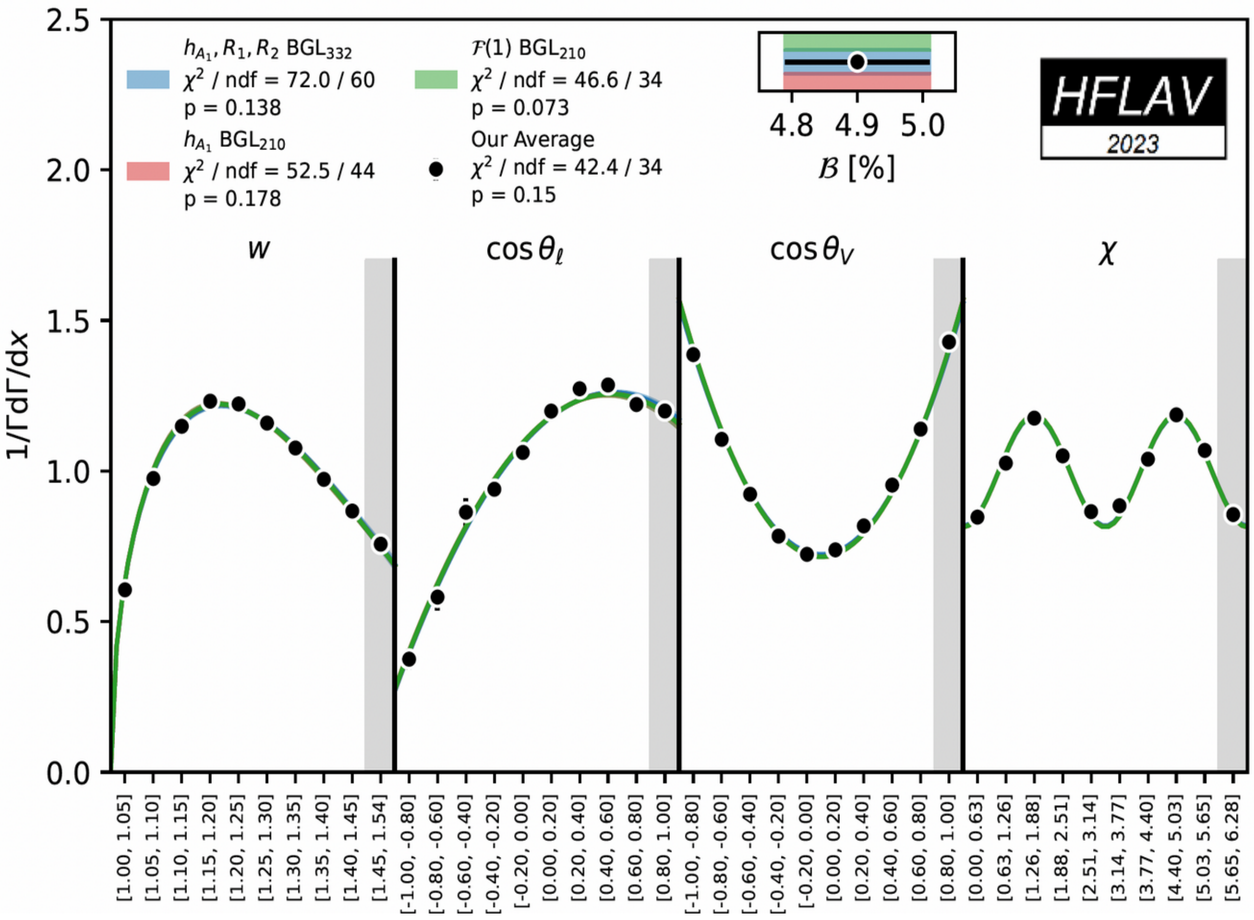
B→D*$\ell\nu$ decays



Belle II 23:
Untagged differential
Branching fraction and projections to differential distributions

	ρ^2	$R_1(1)$	$R_2(1)$	$\lvert V_{cb}\rvert$
Statistical	3.0	4.1	2.8	0.7
Background subtraction	1.4	2.2	1.2	0.3
Size of simulated samples	1.2	1.7	1.1	0.3
Lepton ID efficiency	0.2	1.6	0.1	0.3
Slow pion efficiency	1.0	0.9	0.8	1.5
Tracking of K, π, ℓ				0.4
$N_{B\bar{B}}$				0.8
f_{+0}				1.3
$\mathcal{B}(D^{*+} \to D^0\pi^+)$				0.4
$\mathcal{B}(D^0 \to K^-\pi^+)$				0.4
B^0 lifetime				0.1
Signal modeling	2.6	2.6	2.0	0.5
Total	4.5	5.9	3.9	2.4

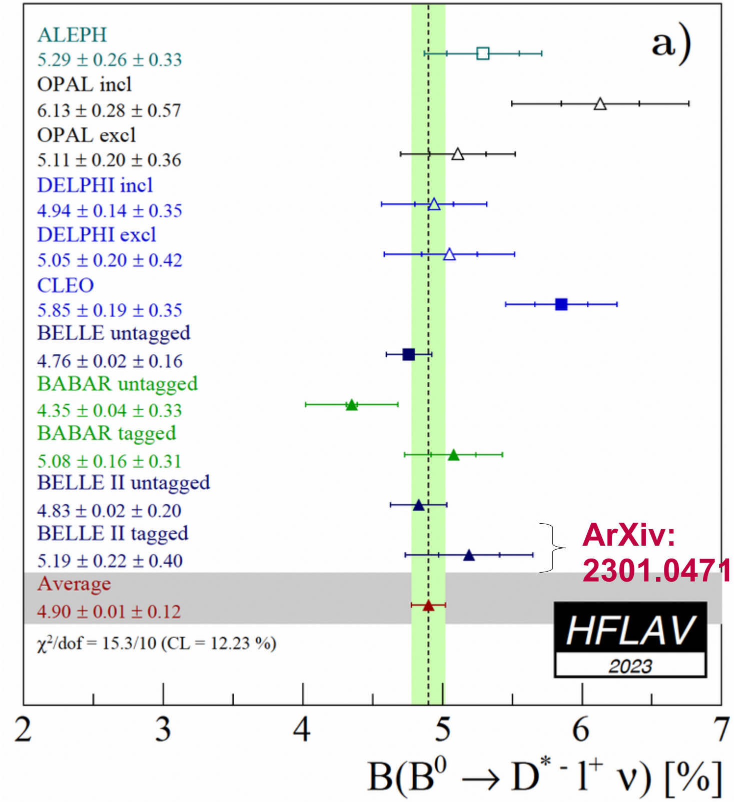
$B \to D^* \ell \nu$ decays: HFLAV 2023



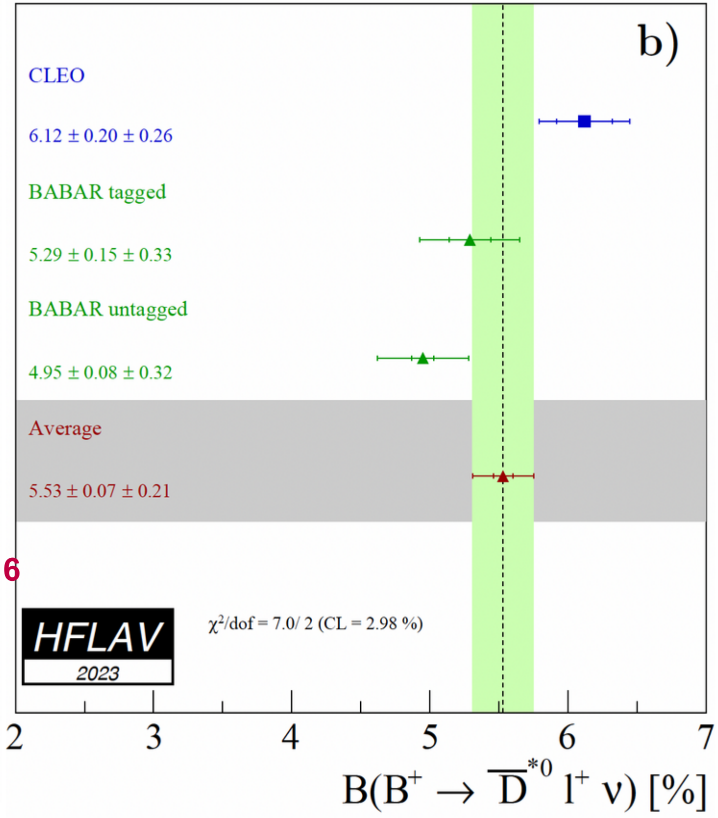
$$\chi^2 = \left(\left(\frac{\Delta\vec{\Gamma}}{\Gamma}\right)^{\mathrm{m}} - \left(\frac{\Delta\,\vec{\Gamma}(\vec{x})}{\Gamma(\vec{x})}\right)^{\mathrm{p}}\right) C_{\mathrm{exp}}^{-1} \left(\left(\frac{\Delta\vec{\Gamma}}{\Gamma}\right)^{\mathrm{m}} - \left(\frac{\Delta\,\vec{\Gamma}(\vec{x})}{\Gamma(\vec{x})}\right)^{\mathrm{p}}\right)^T$$
$$+ \left(\Gamma^{\mathrm{ext}} - \Gamma^{\mathrm{p}}(\vec{x})\right)^2 / \sigma(\Gamma^{\mathrm{ext}})^2$$
$$+ \left(h_X^{\mathrm{p}}(\vec{x}) - h_X^{\mathrm{LQCD}}\right) C_{\mathrm{LQCD}}^{-1} \left(h_X^{\mathrm{p}}(\vec{x}) - h_X^{\mathrm{LQCD}}\right),$$

	Value
$a_0 \times 10^2$	3.08 ± 0.07
$a_1 \times 10^2$	-9.27 ± 2.56
$a_2 \times 10^2$	6.95 ± 44.81
$b_0 \times 10^2$	1.22 ± 0.01
$b_1 \times 10^2$	1.45 ± 0.59
$b_2 \times 10^2$	-49.74 ± 13.46
$c_1 \times 10^2$	-0.11 ± 0.13
$c_2 \times 10^2$	2.19 ± 2.47
$\lvert V_{cb}\rvert \times 10^3$	39.97 ± 0.65

Branching Fractions for B→D*ℓν decays



ArXiv: 2301.04716



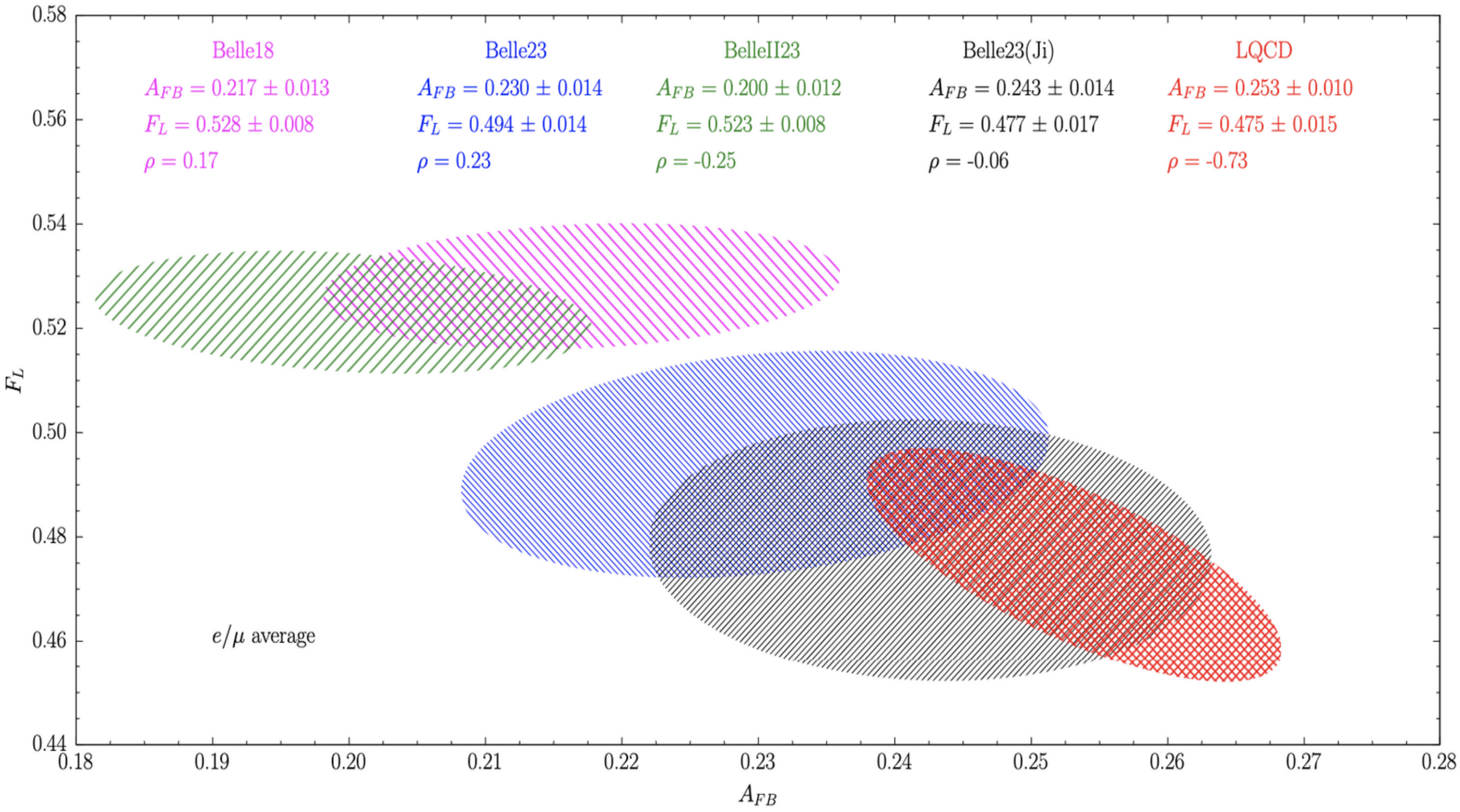
$$\mathcal{B}(\overline{B}^0 \to D^{*+}\ell^-\overline{\nu}_\ell) = (4.90 \pm 0.01 \pm 0.12)\%$$

$$\mathcal{B}(B^- \to D^{*0}\ell^-\overline{\nu}_\ell) = (5.53 \pm 0.07 \pm 0.21)\%$$

$$\mathcal{B}(\overline{B}^0 \to D^{*+}\ell^-\overline{\nu}_\ell) = (4.90 \pm 0.01 \pm 0.11)\%$$

Data-LQCD and angular observables

Simula, Martinelli, Vittorio, 2409.10492



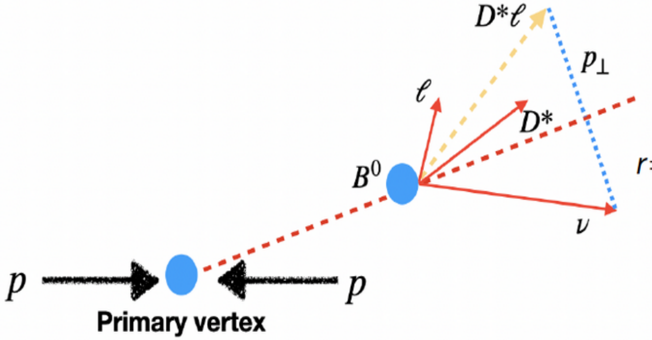
LHCb: neutrino reconstruction

Approximate B rest frame

$$p_z^B = \frac{m_B}{m_{D^*\ell}} p_z^Y \qquad |p_B| = \frac{m_B}{m_{D^*\ell}} p_z^{D^*\ell}\sqrt{1+\tan^2(\alpha_z)}$$

Quadratic equation

$$p^{\perp}_{D^*\ell}\,, \quad p^{\parallel}_{D^*\ell}$$

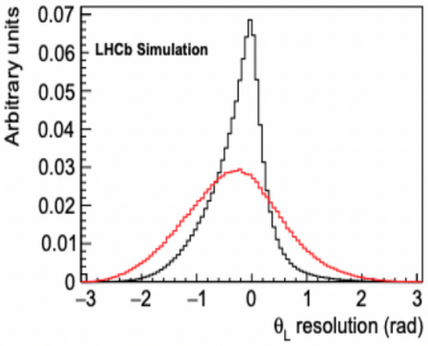


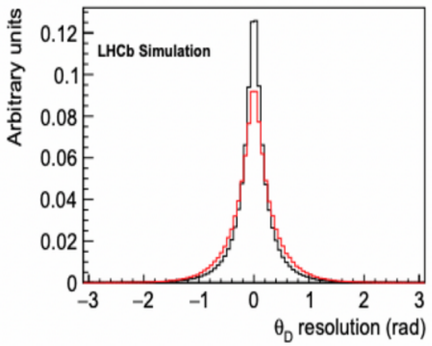
$$a = \frac{p^{\parallel}_{D^*\ell}(m^2 - m^2_{D^*\ell} - 2(p^{\perp}_{D^*\ell})^2)}{2((p^{\perp}_{D^*\ell})^2 - E^2_{vis})}$$

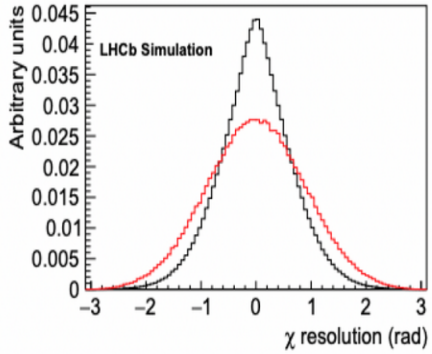
$$r = \frac{E^{\parallel}_{D^*\ell}(m^2 - m^2_{D^*\ell} - 2(p^{\perp}_{D^*\ell})^2)}{4((p^{\perp}_{D^*\ell})^2 - E^2_{vis})^2} + \frac{(E_{D^*\ell}\, p^{\perp}_{D^*\ell})^2}{(p^{\perp}_{D^*\ell})^2 - E^2_{vis}}$$

$$p^+ = p^{\parallel}_{D^*\ell} - a + \sqrt{r}$$

$$p^- = p^{\parallel}_{D^*\ell} - a - \sqrt{r}$$







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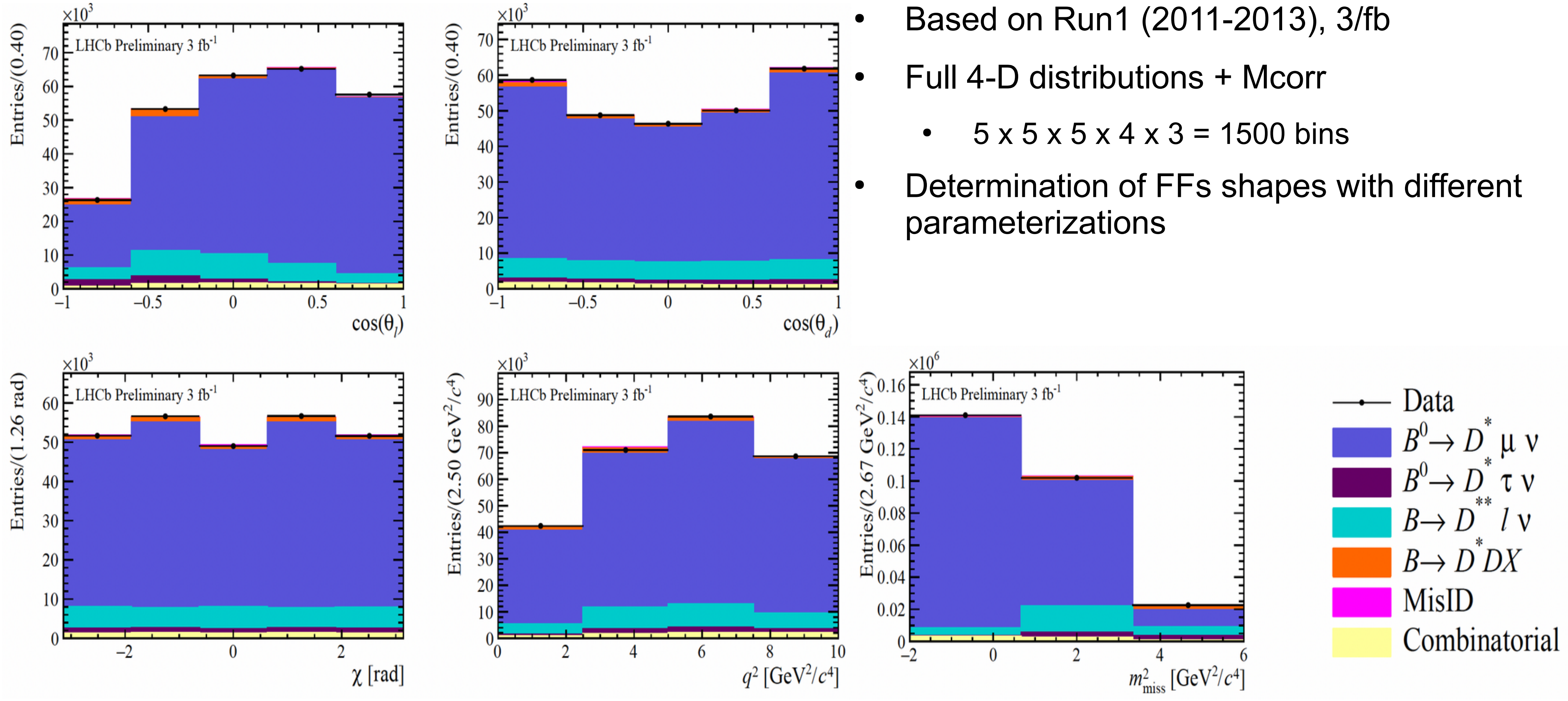
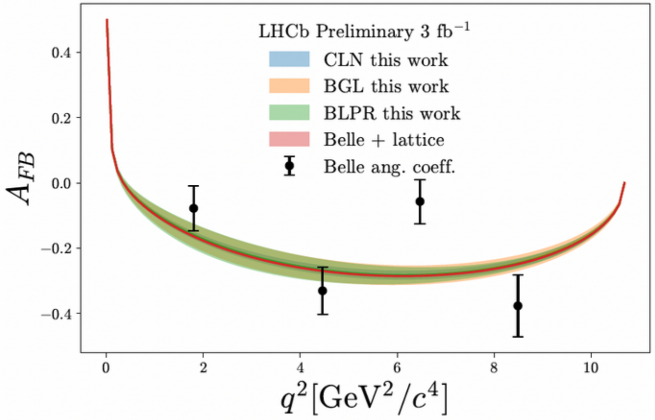
April 2026

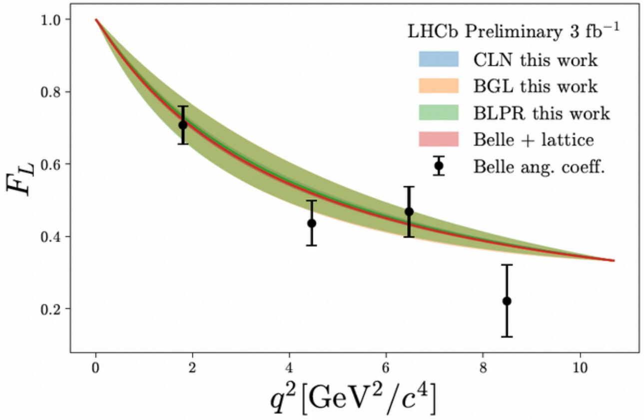
LHCb angular analysis

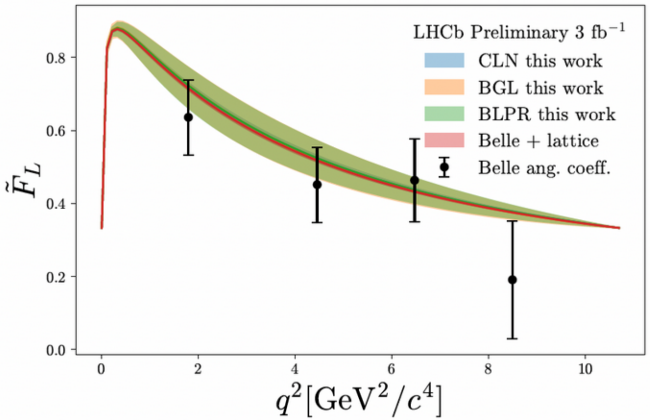


- Based on Run1 (2011-2013), 3/fb
- Full 4-D distributions + Mcorr
  - 5 x 5 x 5 x 4 x 3 = 1500 bins
- Determination of FFs shapes with different parameterizations

Angular observables, indirect determination







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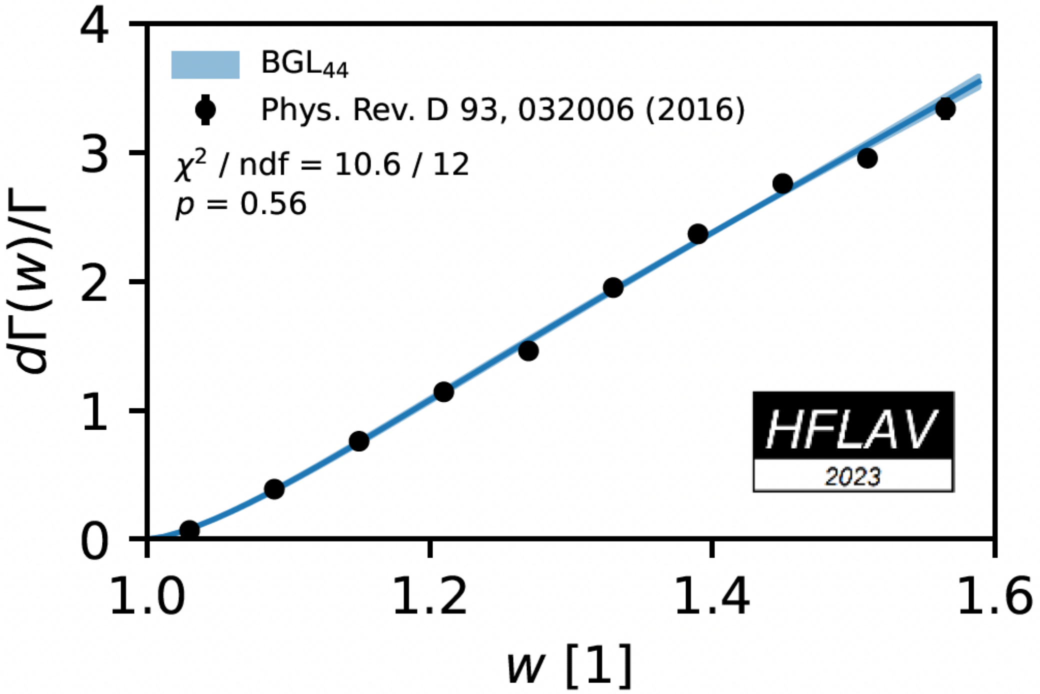
Form factors determined with different parameterizations:

- CLN
- BGL (truncation based on BIC)
- BLPR

- In agreement with:
  - Belle angular coefficient measurement (black markers)
    PRL 133 (2024) 131801
  - BLPR prediction containing lattice and Belle data
    PRD 95 (2018) 115008

$B \to D\ell\nu$ decays: HFLAV2023



	$\sigma\,(\Delta\Gamma_i/\Delta w)[\%]$									
	0	1	2	3	4	5	6	7	8	9
Tag correction	3.0	3.2	3.3	3.4	3.4	3.4	3.4	3.3	3.3	3.2
Charged tracks	1.7	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
$\mathcal{B}(D \to \text{hadronic})$	2.0	1.8	1.8	1.8	1.8	1.8	1.8	1.9	1.9	1.9
$\mathcal{B}(B \to D^{*(*)}\ell\nu)$	1.3	0.8	0.8	0.9	0.8	0.7	0.5	0.2	0.2	0.4
$\mathcal{B}(B \to X_u\ell\nu)$	0.4	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
$\text{FF}(B \to D^*\ell\nu)$	0.4	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.2
$\text{FF}(B \to D^{**}\ell\nu)$	2.5	1.2	0.9	0.7	0.5	0.5	0.7	0.5	0.1	0.4
Signal shape	5.0	0.8	0.6	0.5	0.5	0.4	0.3	0.3	0.2	0.1
Lifetimes	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
π^0 efficiency	0.9	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7
K/π efficiency	1.1	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.0	1.0
K_S efficiency	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Luminosity	1.4	1.4	1.5	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Total	7.3	4.7	4.7	4.7	4.7	4.6	4.7	4.6	4.5	4.5

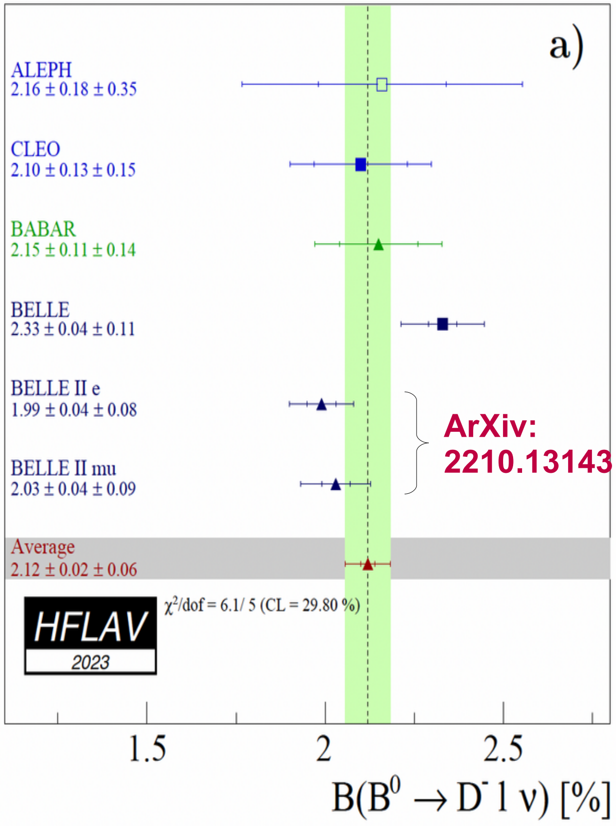
Belle 2016 PRD93 (2016) 032006

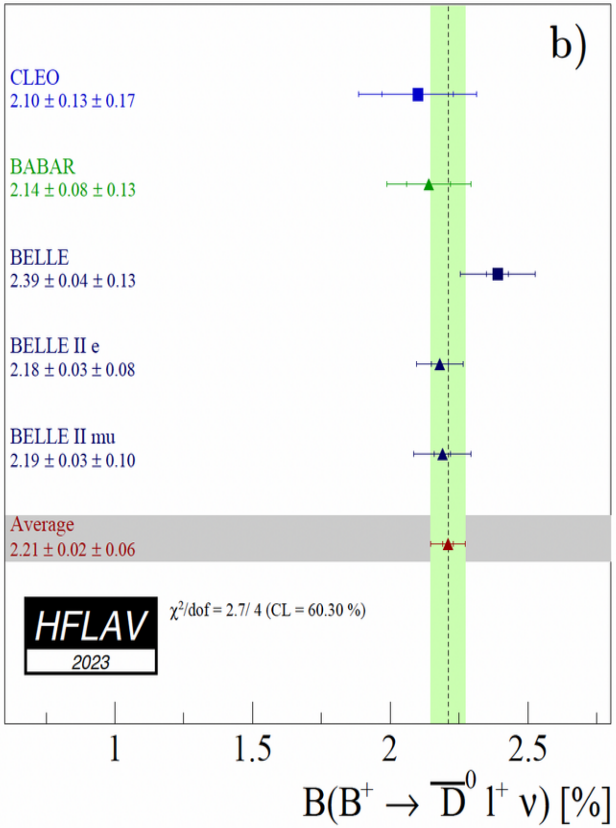
LQCD at non-zero recoil
FNAL/MILC PRD 92 (2015) 034506
HPQCD PRD 92 (2015) 054510

HFLAV23 updated result

$$|V_{cb}| = (38.9 \pm 0.7) \times 10^{-3}$$

B → D$\ell\nu$ decays: Branching Fractions





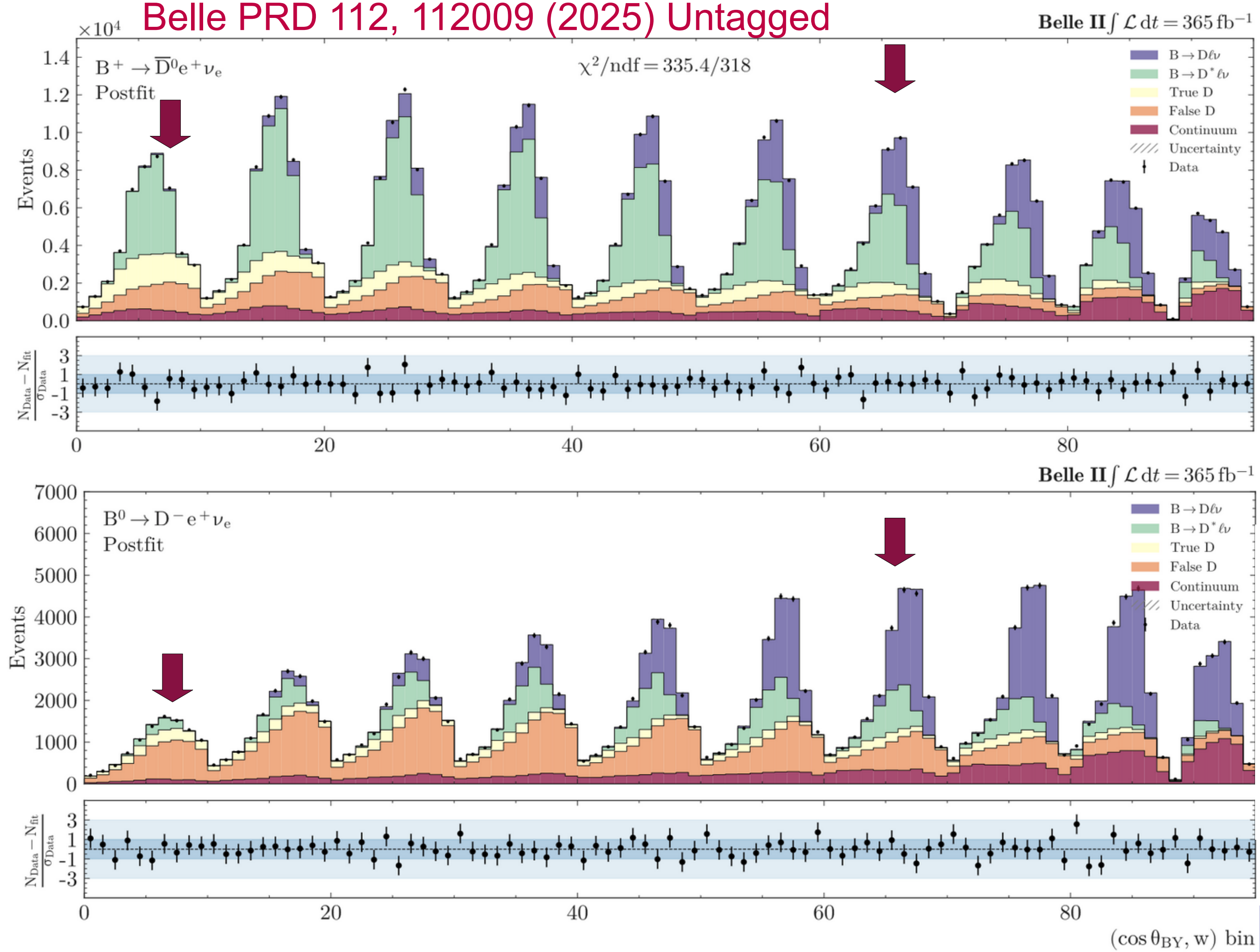
Belle 2016 PRD93 (2016) 032006

Sample	Signal yield	$\mathcal{B}$ [%]
$B^0 \to D^- e^+ \nu_e$	$2848 \pm 72 \pm 17$	$2.44 \pm 0.06 \pm 0.12$
$B^0 \to D^- \mu^+ \nu_\mu$	$2302 \pm 63 \pm 13$	$2.39 \pm 0.06 \pm 0.11$
$B^+ \to \bar{D}^0 e^+ \nu_e$	$6456 \pm 126 \pm 66$	$2.57 \pm 0.05 \pm 0.13$
$B^+ \to \bar{D}^0 \mu^+ \nu_\mu$	$5386 \pm 110 \pm 51$	$2.58 \pm 0.05 \pm 0.13$
$B^0 \to D^- \ell^+ \nu_\ell$	$5150 \pm 95 \pm 29$	$2.39 \pm 0.04 \pm 0.11$
$B^+ \to \bar{D}^0 \ell^+ \nu_\ell$	$11843 \pm 167 \pm 120$	$2.54 \pm 0.04 \pm 0.13$
$B \to D \ell \nu_\ell$	$16992 \pm 192 \pm 142$	$2.31 \pm 0.03 \pm 0.11$

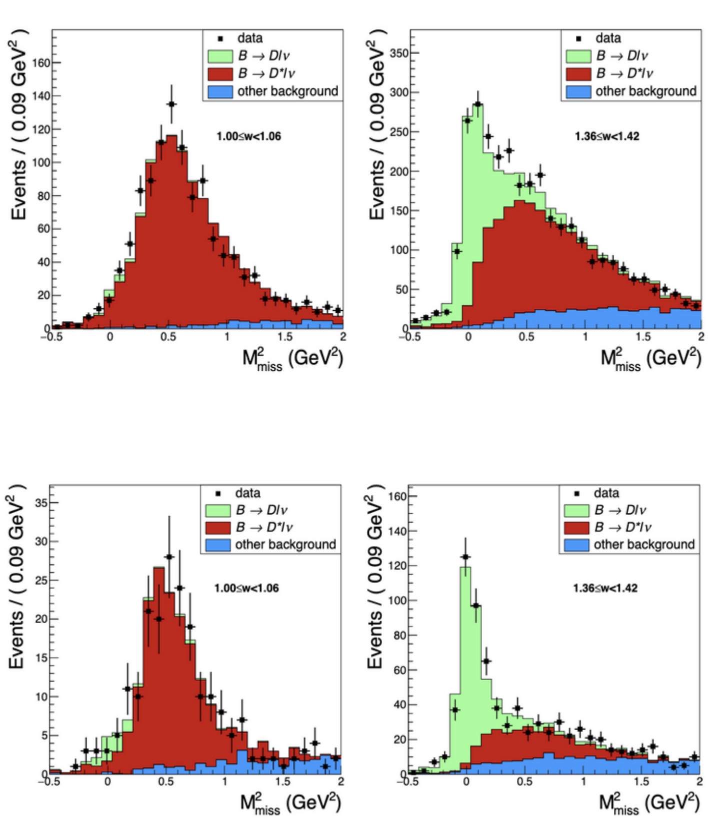
D’Agostini bias at work?
Jung, Schacht arXiv:2604.08391

New Belle II B → Dℓν decays

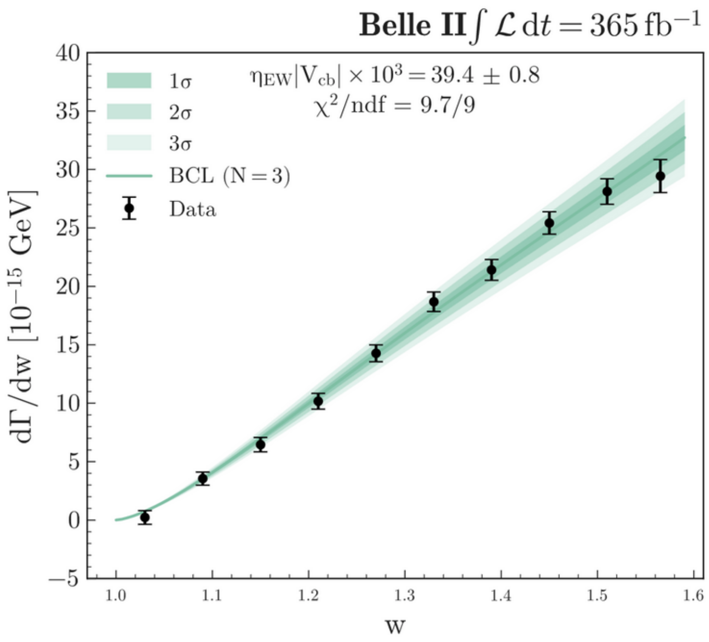
Belle PRD 112, 112009 (2025) Untagged



Belle PRD 93 (2016) 032006
Hadronic tagged



Belle II B→D$\ell\nu$ decays



$$|V_{cb}|_{\mathrm{BCL}} = (39.2 \pm 0.4\,(\mathrm{stat.}) \pm 0.6\,(\mathrm{sys.}) \pm 0.5\,(\mathrm{th.})) \times 10^{-3}$$

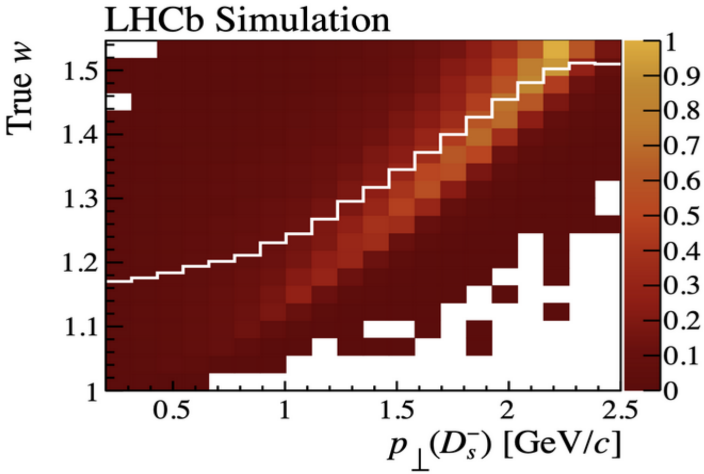
Source		Uncertainty [%]
Statistical		0.9
Systematic		1.5
	$B^{0/+}$ lifetime	0.1
	Signal form factor	0.1
	$B \to D^*\ell\nu$ form factor	0.1
	$\mathcal{B}(B \to X_c\ell\nu)$	0.3
	$\mathcal{B}(D \to K\pi(\pi))$	0.5
	Tracking efficiency	0.5
	$N_{\Upsilon(4S)}$	0.7
	f_{00}/f_{+-}	0.1
	$f_{\not{B}}$	0.4
	Background w modelling	0.3
	(E^*_Y, m_Y) reweighting	0.3
	Lepton identification	0.3
	Kaon identification	0.6
	Vertex fit χ^2 correction	0.3
	Simulation sample size	0.5
Theoretical		1.3
	Lattice QCD inputs	1.2
	Long-distance QED	0.5
Total		2.1

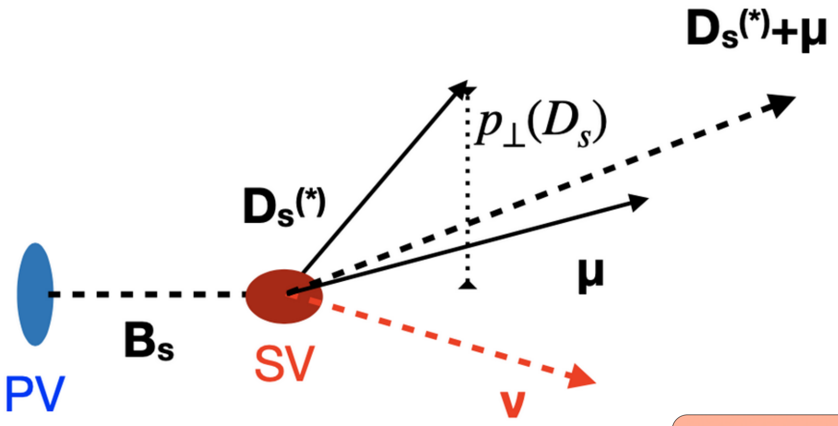
LHCb Measurement of $|V_{cb}|$ with B_s decays

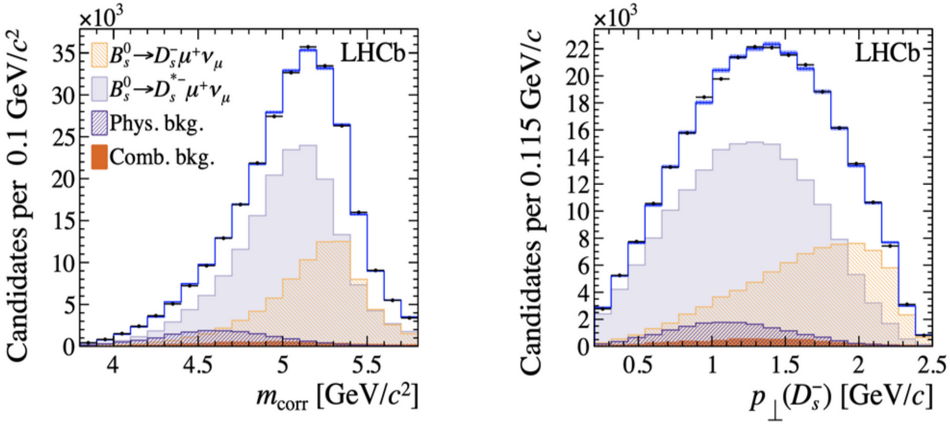
ArXiv:2001.03225

- Extract $|V_{cb}|$ from B_s decays $B_s \to D_s \mu\nu$ and $B_s \to D_s^* \mu\nu$
- Normalized to $B^0 \to D^- \mu\nu$ and $B^0 \to D^{*-} \mu\nu$

$$\mathcal{R} \equiv \frac{\mathcal{B}(B_s \to D_s \mu\nu)}{\mathcal{B}(B^0 \to D^- \mu\nu)} = \boxed{\frac{N_s}{N_d} \cdot \frac{\epsilon_d}{\epsilon_s}} \cdot \boxed{\frac{f_d}{f_s} \cdot \frac{\mathcal{B}(D^- \to KK\pi)}{\mathcal{B}(D_s \to KK\pi)}}$$





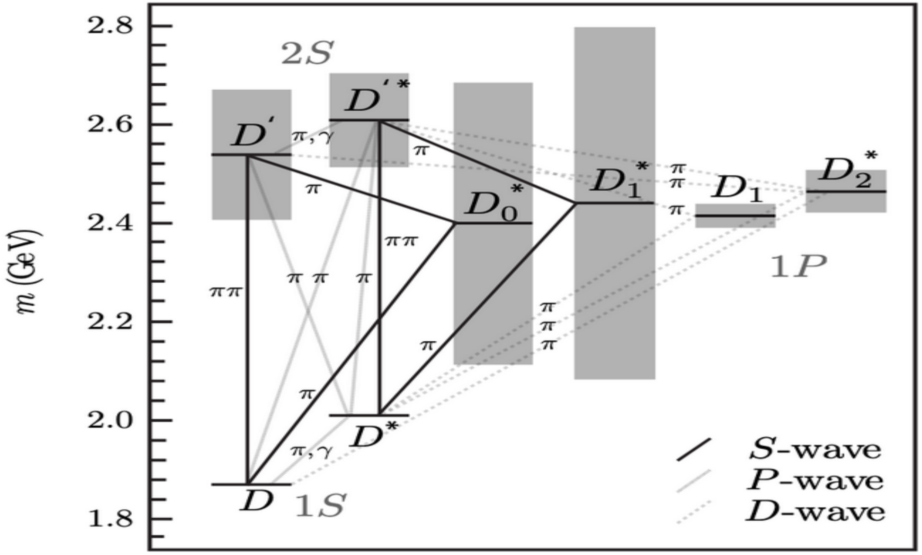


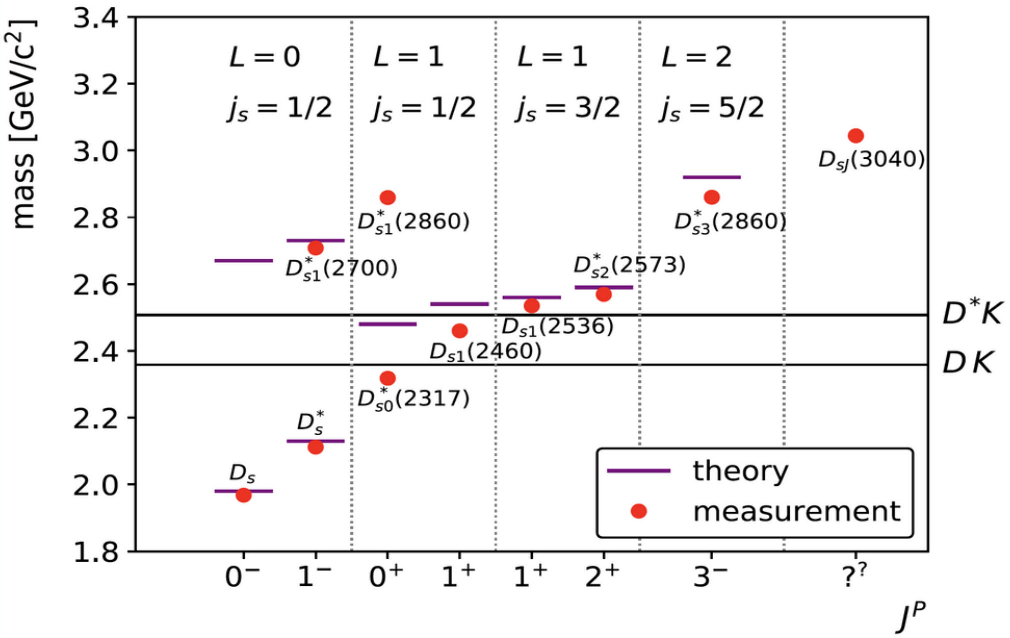
$$|V_{cb}|_{\mathrm{BGL}} = (41.2 \pm 0.8 \pm 0.9 \pm 0.8) \times 10^{-3}$$

B_s semileptonic decays

- Complementary measurements to those from B^0 and B^+
- Advantages:
  - Lattice calculations easier due to heavier spectator quark, so predictions are more precise
  - For the $B_s \to D_s^*$: the *zero-width* approximation of the D_s^* is more valid than the B case (no $D\pi$ pollution)
  - Experimental point: different background composition from excited D_s states than in the $B \to D^*$ case

Golden modes for Lattice-QCD





Analyse B → D$\ell\nu$ and B→D*$\ell\nu$ together

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April 2026

First simultaneous analysis of $B \to D\ell\nu$ and $B \to D^*\ell\nu$ at Belle II where D^* is partially reconstructed:

1. Get rid of major systematic uncertainty on $B \to D^*\ell\nu$ analysis (slow pion efficiency)

2. Analyse together $\overline{D}^0\ell^+$ and $D^-\ell^+$ decays and impose equal SL decay widths for B^0 and B^+:

$$\Gamma(B^0 \to D^{(*)-}\ell^+\nu_\ell) = \Gamma(B^+ \to \overline{D}^{(*)0}\ell^+\nu_\ell)$$

Using the constraint $f_{+-} + f_{00} + f_{noB\bar{B}} = 1$, determine:

$f_{+-}/f_{00} = \mathcal{B}(\Upsilon(4S) \to B^+B^-)/\mathcal{B}(\Upsilon(4S) \to B^0\bar{B}^0)$ for the first time at Belle II

Important input for any B branching-fraction measurement at B-factories

Expected world's best measurements

$\mathcal{B}(B^+ \to \overline{D}^0\ell^+\nu) = (XXX \pm 0.01 \pm 0.06)\,\%$

$\mathcal{B}(B^+ \to \overline{D}^{*0}\ell^+\nu) = (XXX \pm 0.02 \pm 0.15)\,\%$

$\mathcal{B}(B^0 \to D^-\ell^+\nu) = (XXX \pm 0.01 \pm 0.06 \pm 0.02)\,\%$

$\mathcal{B}(B^0 \to D^{*-}\ell^+\nu) = (XXX \pm 0.02 \pm 0.14 \pm 0.06)\,\%$

$f_{+-}/f_{00} = XXX \pm 0.007 \pm 0.024 \pm 0.024$

$|V_{cb}|\,[10^{-3}] = XXX \pm 0.12 \pm 0.58 \pm 0.23$

Unblinding started

$|V_{cb}|$ inclusive

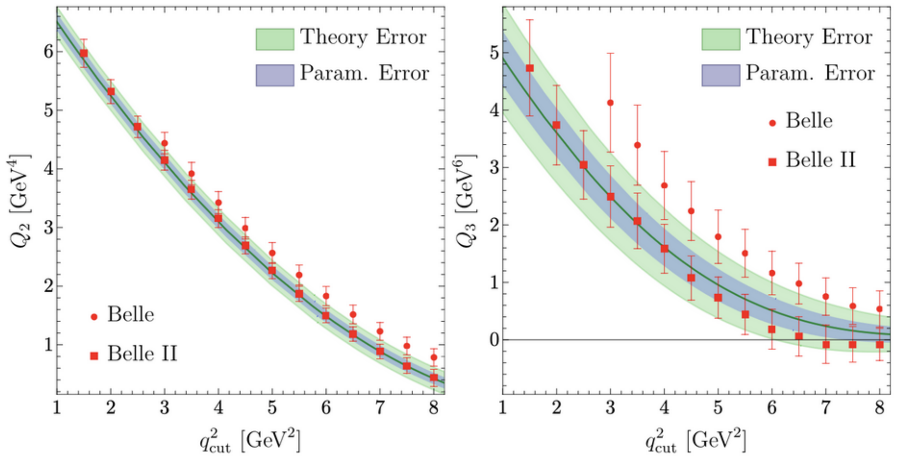
- HQE is the successful tool to include perturbative and non-perturbative QCD corrections that allow to connect measurements of semileptonic B-meson decays to $|V_{cb}|^2$

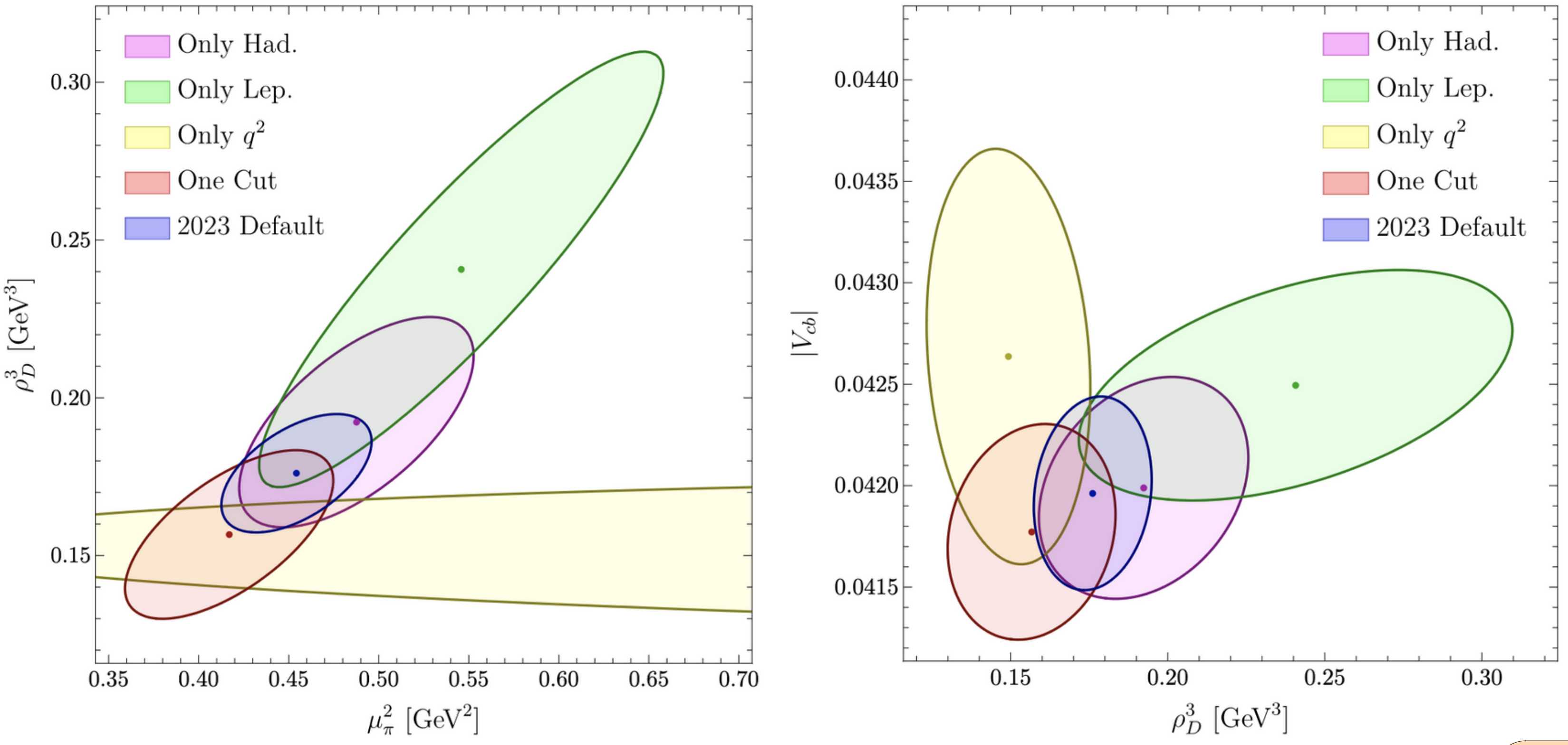
$$\Gamma_{sl} = \Gamma_0 \Big[1 + a^{(1)} \frac{\alpha_s(m_b)}{\pi} + a^{(2,\beta_0)} \beta_0 \left(\frac{\alpha_s}{\pi}\right)^2 + a^{(2)} \left(\frac{\alpha_s}{\pi}\right)^2 + \left(-\frac{1}{2} + p^{(1)} \frac{\alpha_s}{\pi}\right) \frac{\boxed{\mu_\pi^2}}{\boxed{m_b^2}} + \left(g^{(0)} + g^{(1)} \frac{\alpha_s}{\pi}\right) \frac{\boxed{\mu_G^2}(m_b)}{\boxed{m_b^2}} + d^{(0)} \frac{\boxed{\rho_D^3}}{\boxed{m_b^3}} - g^{(0)} \frac{\boxed{\rho_{LS}^3}}{\boxed{m_b^3}} + \text{higher orders} \Big]$$

No new experimental results on hadroni and lepton moments from 2010

Experiment	Hadron moments <M^n_X>	Lepton moments <E^n_l>	References
BaBar	n=2 c=0.9,1.1,1.3,1.5 n=4 c=0.8,1.0,1.2,1.4 n=6 c=0.9,1.3 [1]	n=0 c=0.6,1.2,1.5 n=1 c=0.6,0.8,1.0,1.2,1.5 n=2 c=0.6,1.0,1.5 n=3 c=0.8,1.2 [1,2]	[1] Phys.Rev. D81 (2010) 032003 [2] Phys.Rev. D69 (2004) 111104
Belle	n=2 c=0.7,1.1,1.3,1.5 n=4 c=0.7,0.9,1.3 [3]	n=0 c=0.6,1.4 n=1 c=1.0,1.4 n=2 c=0.6,1.4 n=3 c=0.8,1.2 [4]	[3] Phys.Rev. D75 (2007) 032005 [4] Phys.Rev. D75 (2007) 032001
CDF	n=2 c=0.7 n=4 c=0.7 [5]	.	[5] Phys.Rev. D71 (2005) 051103
CLEO	n=2 c=1.0,1.5 n=4 c=1.0,1.5 [6]	.	[6] Phys.Rev. D70 (2004) 032002
DELPHI	n=2 c=0.0 n=4 c=0.0 n=6 c=0.0 [7]	n=1 c=0.0 n=2 c=0.0 n=3 c=0.0 [7]	[7] Eur.Phys.J. C45 (2006) 35-59

Moments in q2 from Belle (2021) and Belle 2 (2022)



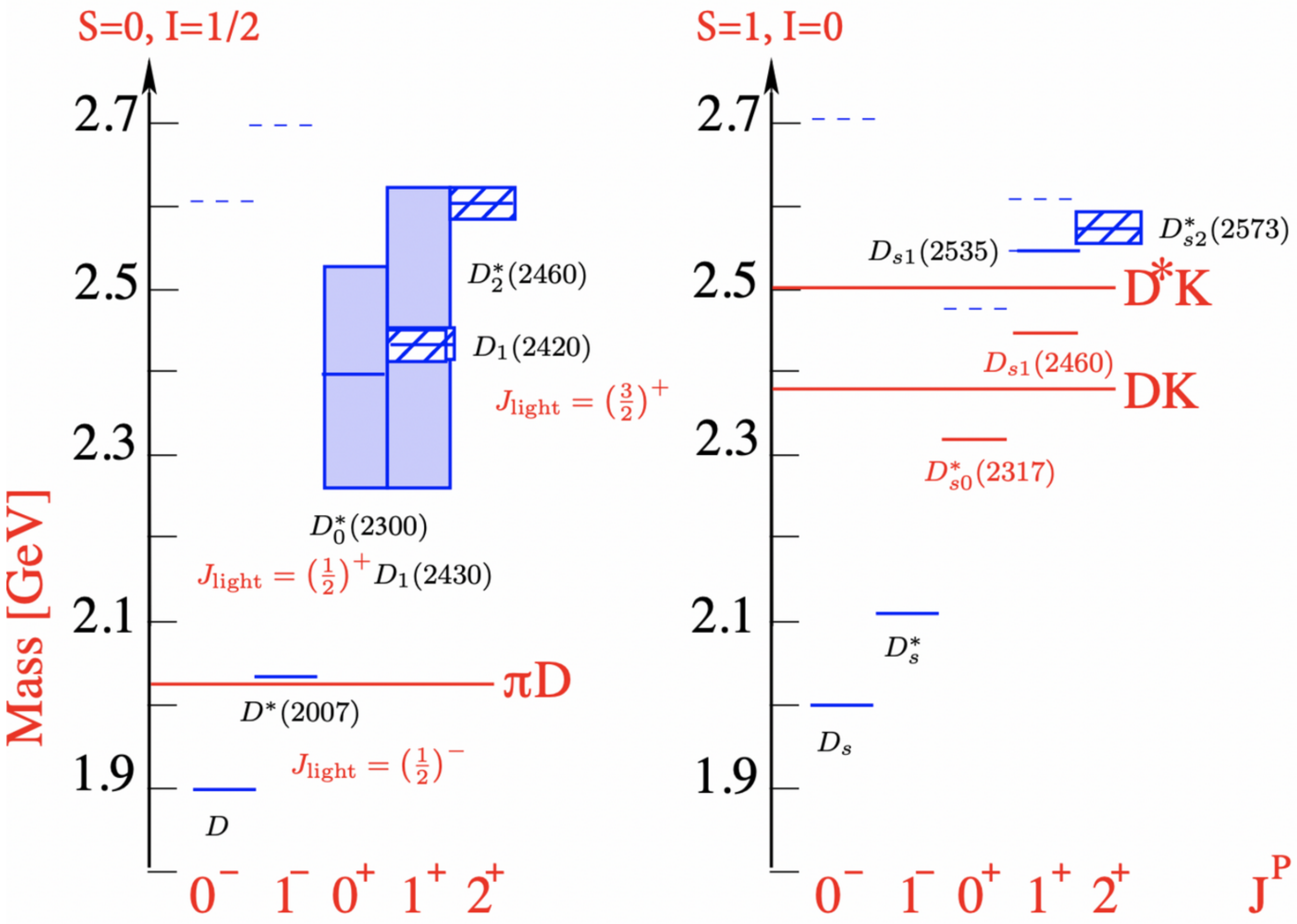


Gambino, Finauri 23

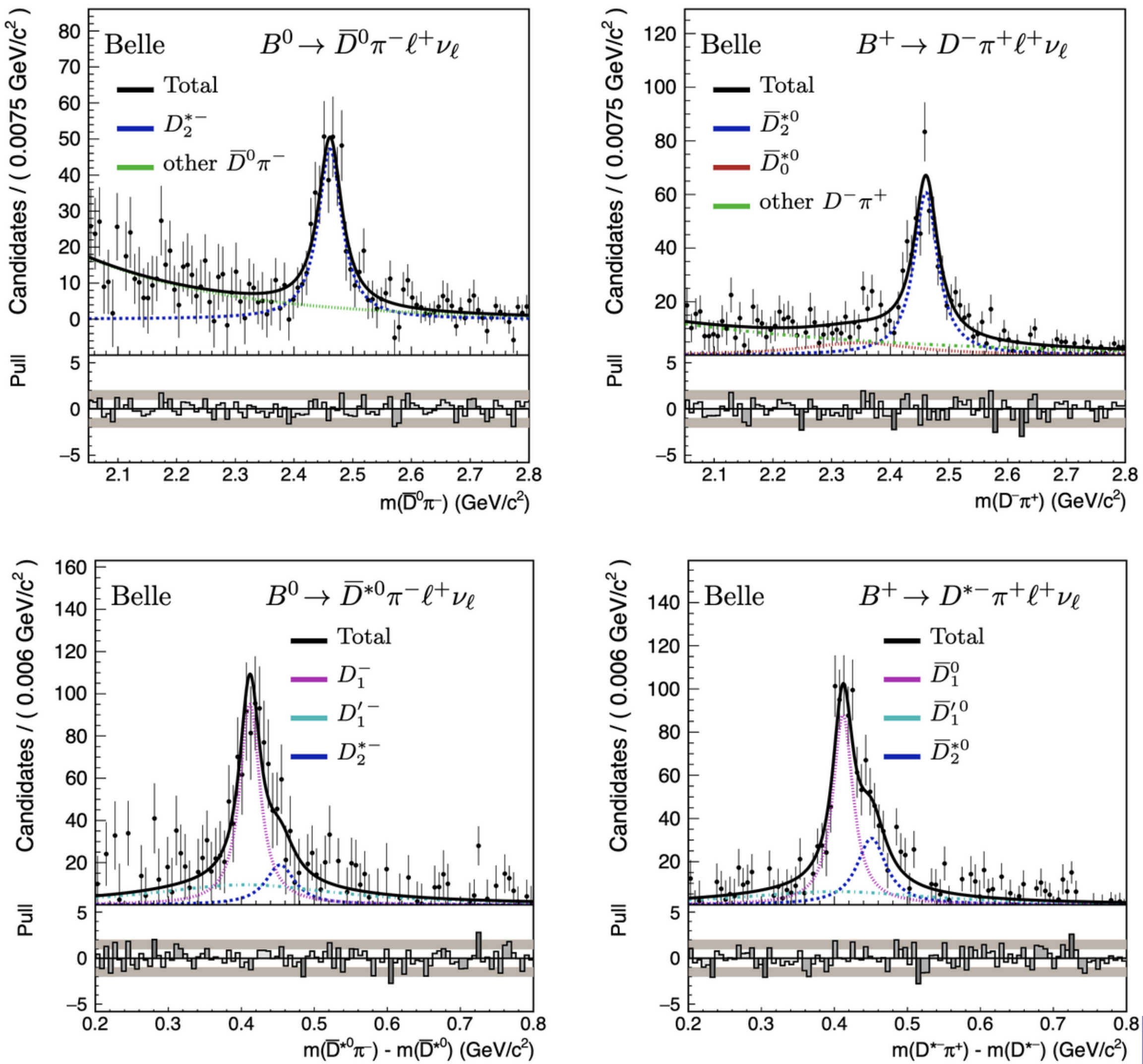
Inclusive BF
need to be updated

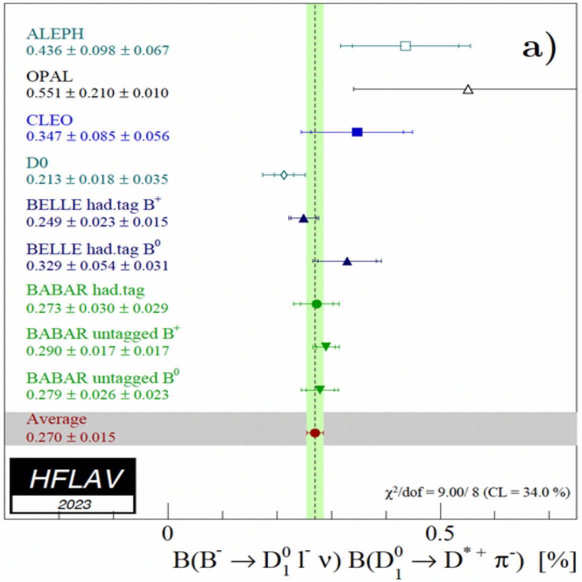
$m_b^{\rm kin}$	$\overline{m}_c(2\,\mathrm{GeV})$	μ_π^2	$\mu_G^2(m_b)$	$\rho_D^3(m_b)$	ρ_{LS}^3	$\mathrm{BR}_{c\ell\nu}$	$10^3\|V_{cb}\|$
4.573	1.090	0.454	0.288	0.176	−0.113	10.63	41.97
0.012	0.010	0.043	0.049	0.019	0.090	0.15	0.48

$B \to D^{**}\ell\nu$

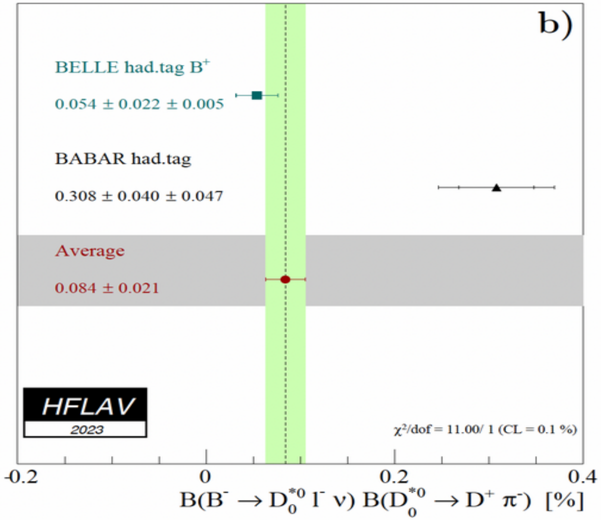

S=0, I=1/2
S=1, I=0
Mass [GeV]
2.7
2.5
2.3
2.1
1.9
$D_2^*(2460)$
$D_1(2420)$
$J_{\rm light} = (\frac{3}{2})^+$
$D_0^*(2300)$
$J_{\rm light} = (\frac{1}{2})^+$ $D_1(2430)$
πD
$D^*(2007)$
$J_{\rm light} = (\frac{1}{2})^-$
D
$D_{s2}^*(2573)$
$D_{s1}(2535)$
D*K
$D_{s1}(2460)$
DK
$D_{s0}^*(2317)$
D_s^*
D_s
0^- 1^- 0^+ 1^+ 2^+
0^- 1^- 0^+ 1^+ 2^+ J^P

$B \to D^{**}\ell\nu$



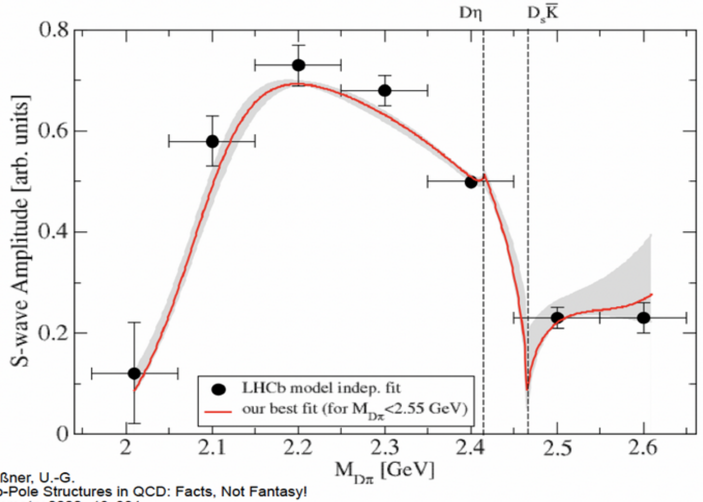


Belle 2022

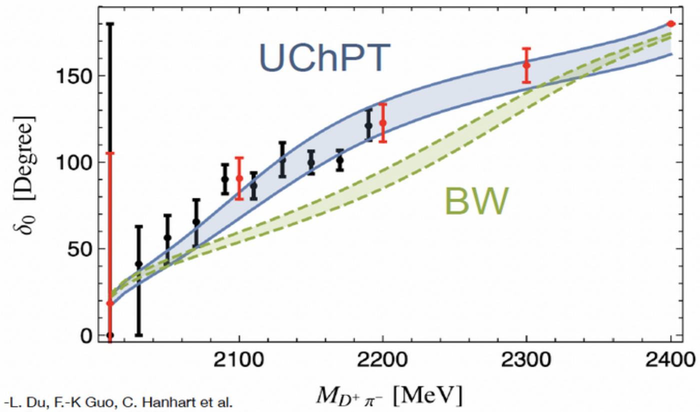


$D_0^*(2300)$
Modeled with BW

What is the D_0^* ?



Meißner, U.-G.
Two-Pole Structures in QCD: Facts, Not Fantasy!
Symmetry 2020, *12*, 981.
https://doi.org/10.3390/sym12060981



M. -L. Du, F.-K Guo, C. Hanhart et al.
Phys. Rev. Lett. 126, 192001
https://doi.org/10.1103/PhysRevLett.126.192001

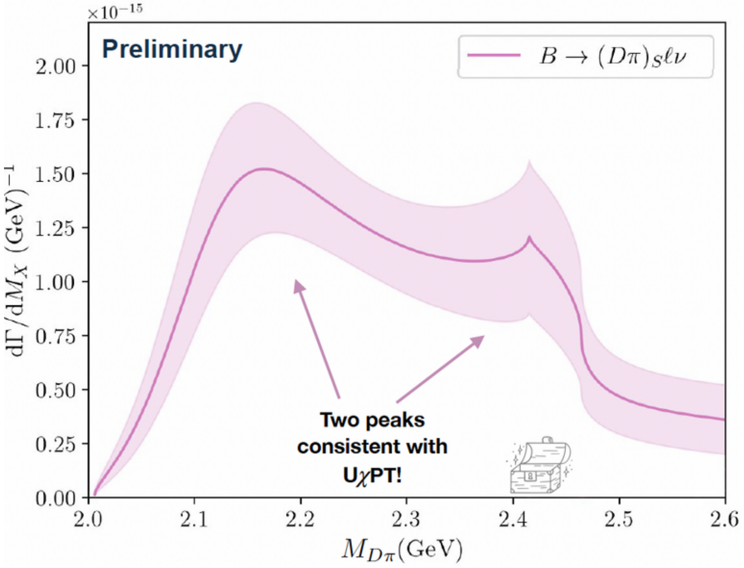
- $D_0^*(2300)$ a two pole structure with poles near

→ $(2.1 - i\ 0.1)$ GeV

→ $(2.45 - i\ 0.13)$ GeV

SU(3) partner of D_{s0}^* (2.3 GeV)

Nada Gharbi
Bad Honnef 2026



Reanalyzing Belle 2022
Semileptonic analysis

The 'gap'

Branching fractions using averages from HFLAV 2023:

Phys.Rev.D 113 (2026) 1, 012008

Decay	$\mathcal{B}(B^+)$	$\mathcal{B}(B^0)$
$B \to D\ell\nu_\ell$	$(2.27 \pm 0.06) \cdot 10^{-2}$	$(2.11 \pm 0.05) \cdot 10^{-2}$
$B \to D^*\ell\nu_\ell$	$(5.27 \pm 0.12) \cdot 10^{-2}$	$(4.90 \pm 0.11) \cdot 10^{-2}$
$B \to D_1\ell\nu_\ell$	$(6.4 \pm 1.0) \cdot 10^{-3}$	$(5.9 \pm 1.0) \cdot 10^{-3}$
$B \to D_0^*\ell\nu_\ell$	$(0.8 \pm 0.4) \cdot 10^{-3}$	$(0.8 \pm 0.3) \cdot 10^{-3}$
$B \to D_1'\ell\nu_\ell$	$(2.8 \pm 0.4) \cdot 10^{-3}$	$(2.6 \pm 0.4) \cdot 10^{-3}$
$B \to D_2^*\ell\nu_\ell$	$(3.2 \pm 0.3) \cdot 10^{-3}$	$(3.0 \pm 0.3) \cdot 10^{-3}$
$B \to D\pi\pi\ell\nu_\ell$	$(0.7 \pm 0.9) \cdot 10^{-3}$	$(0.7 \pm 0.8) \cdot 10^{-3}$
$B \to D^*\pi\pi\ell\nu_\ell$	$(2.2 \pm 1.0) \cdot 10^{-3}$	$(2.0 \pm 1.0) \cdot 10^{-3}$
$B \to D_sK\ell\nu_\ell$	$(0.30 \pm 0.13) \cdot 10^{-3}$	-
$B \to D_s^*K\ell\nu_\ell$	$(0.29 \pm 0.19) \cdot 10^{-3}$	-
	$(1.78 \pm 0.33)\%$	$(1.81 \pm 0.24)\%$
$B \to X_c\ell\nu_\ell$	$(11.05 \pm 0.16) \cdot 10^{-2}$	$(10.27 \pm 0.15) \cdot 10^{-2}$

$B \to \Lambda_c p \ell \nu$

$B \to D_1(\to D\gamma)\ell\nu$

$B \to D^{(*)} K^+K^-\ell\nu$

$B \to D^{(*)}{}_s K^*\ell\nu$

$B \to D^{**}{}_s K\ell\nu$

...

F.Herren,
R. van Tonder
ArXiv:2605.03021

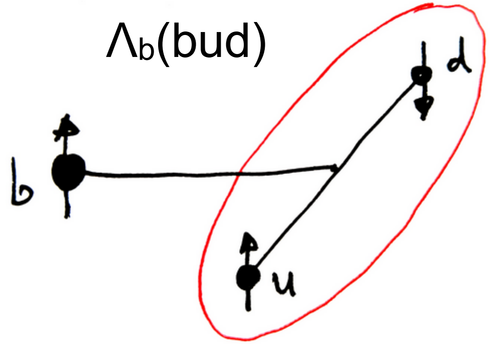
...And many more modes! There is no singular Gap Mode that will close the SL gap.

Baryons Qqq'

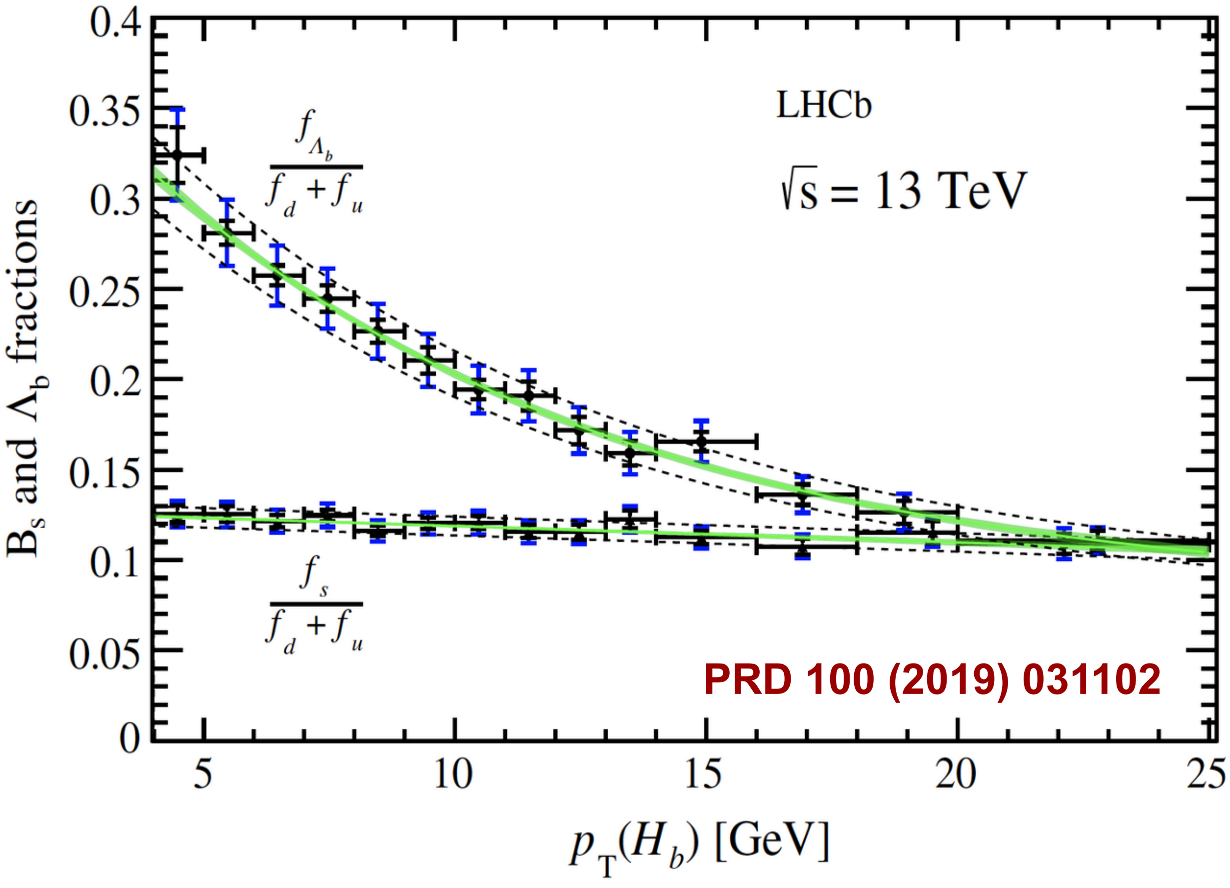
	Baryons	Quarks	Isospin	Mass (MeV)	1^{st} Experimental Evidence	
$J^P = 1/2^+$						
	Λ_b^0	(bud)	0	5619.4 ± 0.7	CERN, 1981	[133]
	Σ_b^+	(buu)	1	5811.3 ± 1.9	CDF, 2007	[134]
	Σ_b^-	(bdd)	1	5815.5 ± 1.8	CDF, 2007	[134]
	Ξ_b^0	(bsu)	1/2	5788 ± 5	DELPHI, 1995	[135]
	Ξ_b^-	(bsd)	1/2	5791.1 ± 2.2	CDF, 2007	[136]
	Ω_b^-	(bss)	0	6071 ± 40	D0, 2008	[137]

- Λ_b is the Lightest b-baryon
- Λ_b spin ~ spin of the b-quark

$\Lambda_b(bud)$



Baryon production



Production fraction averaged in:
- pT in (4, 25) GeV : η in (2, 5)
  - Λ_b : 0.259 ± 0.018
  - B_s : 0.122 ± 0.006

Λ_b fraction is not universal
- depends strongly on transverse momentum
- particle multiplicity of the collision

Crucial for a correct normalization of b-hadron branching fraction measurements

LHCb: unique capability with baryon decays

Γ_{55}	$\Lambda_c^+ \ell^- \overline{\nu}_\ell$ anything	(10.9 ± 2.2) %
Γ_{56}	$\Lambda_c^+ \ell^- \overline{\nu}_\ell$	$(6.2^{+1.4}_{-1.3})$ %
Γ_{57}	$\Lambda_c^+ \tau^- \overline{\nu}_\tau$	(1.9 ± 0.5) %
Γ_{58}	$\Lambda_c^+ \pi^+ \pi^- \ell^- \overline{\nu}_\ell$	(5.6 ± 3.1) %
Γ_{59}	$\Lambda_c(2595)^+ \ell^- \overline{\nu}_\ell$	$(7.9^{+4.0}_{-3.5}) \times 10^{-3}$
Γ_{60}	$\Lambda_c(2625)^+ \ell^- \overline{\nu}_\ell$	$(1.3^{+0.6}_{-0.5})$ %
Γ_{61}	$\Sigma_c(2455)^0 \pi^+ \ell^- \overline{\nu}_\ell$	
Γ_{62}	$\Sigma_c(2455)^{++} \pi^- \ell^- \overline{\nu}_\ell$	

PDG 2025

What we know about $b \to c\, \ell \nu$

Inputs from DELPHI and CDF

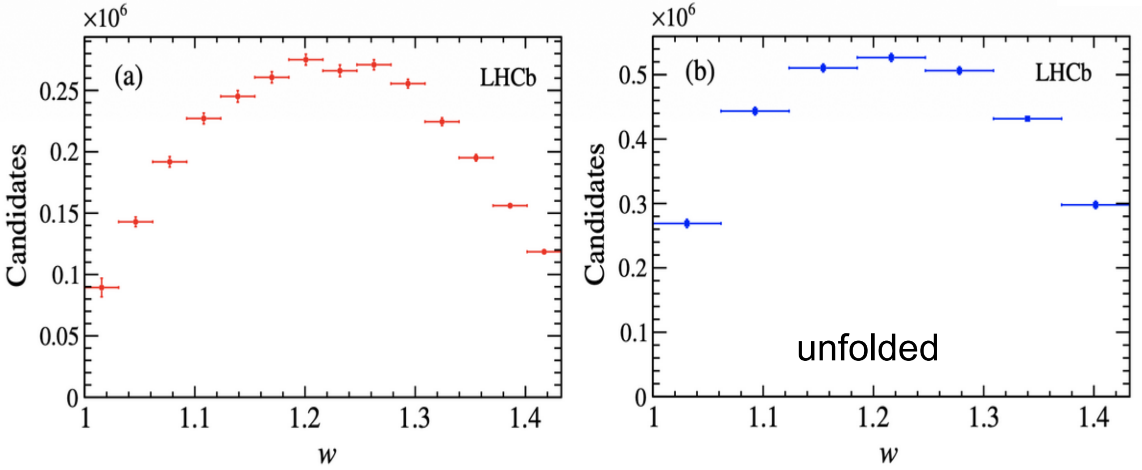
Ground state Λ_c ~ 60% total SL rate

Large uncertainties in the BF

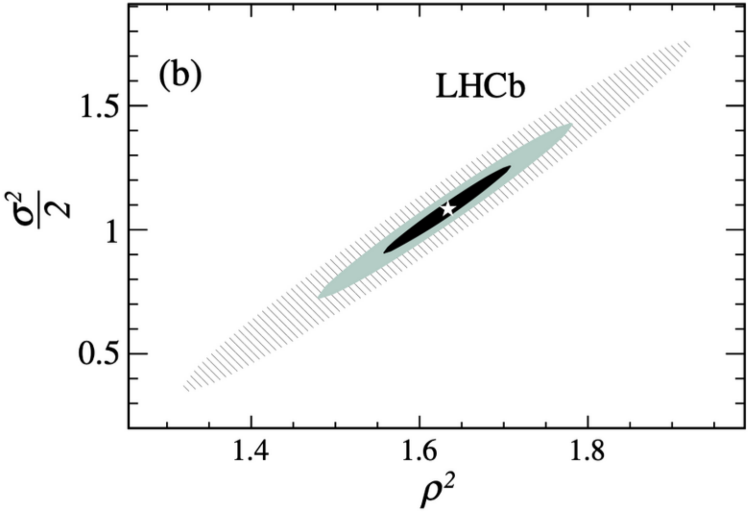
$\Lambda_b \to \Lambda_c$ studies

- Determine the $d\Gamma/dw^2$ differential shape

$$w = (m^2_{\Lambda_b^0} + m^2_{\Lambda_c^+} - q^2)/(2m_{\Lambda_b^0}m_{\Lambda_c^+})$$



$$\xi_B(w) = 1 - \rho^2(w-1) + \frac{1}{2}\sigma^2(w-1)^2 + \cdots$$



$\Lambda_b \to \Lambda_c$ studies: 2-D differential rate and Vcb

Plans

- Determine double differential distributions q2-cos(thetaL)
- Extract form factor and Wilson Coefficients
- Future: study additinal angular observables from 2-body Λ_c decays

$|V_{cb}|$

- Cannot use exclusive B SL decays for normalization, as is done for Bs
- Equality of total semileptonic decay width Bigi et al. JHQP09(2011) 012
  - $\Gamma(\Lambda_b) \sim \Gamma(B_s) \sim \Gamma(B_d)$
- Measure the ratio $N(\Lambda_b \to \Lambda_c\, \mu\nu)/N(\Lambda_b \to X_c\, \mu\nu)$

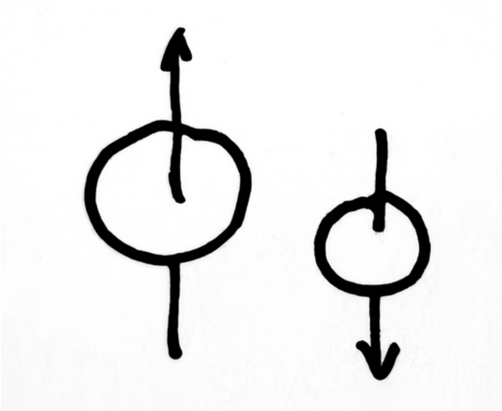
$$\Gamma_{SL}(\Lambda_b) = \Gamma_{SL}(B_d)\left[1 + \delta\right]$$

$$\delta = (4.1 \pm 1.6)\,\%$$

Bordone, Gambino
ArXiv 2203.13107

B_c

- Meson with 2-heavy quarks with open flavor (bc)
- Non-relativistic Qq system: mass spectrum similar to quarkonium
- Decays only via the weak interaction; absolute branching fractions are not known
- Not accessible at B-Factories
- Production rate f(Bc)/f(B+) ~ 1%
- Lifetime 1/3 of other light b-mesons

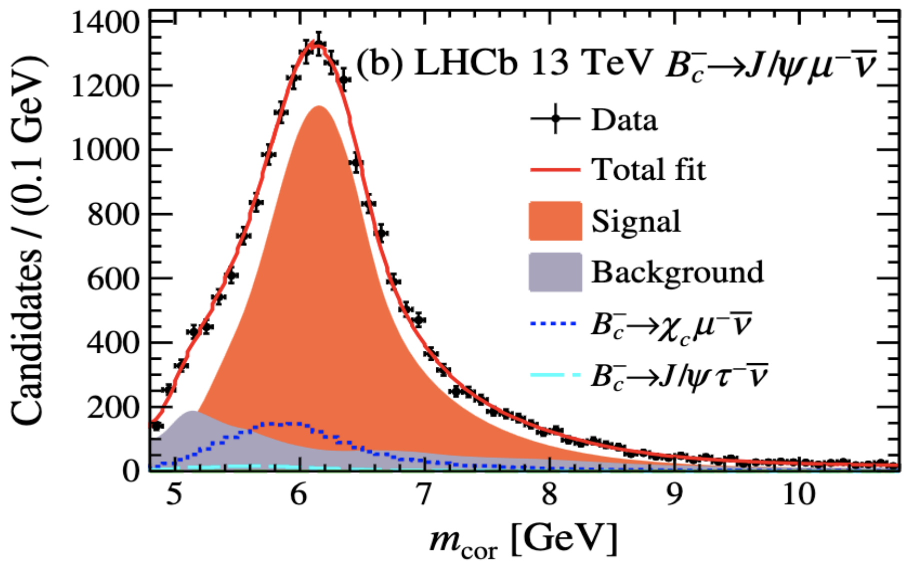


Meson	Mass	Lifetime
B_u	$5.28\ \mathrm{GeV}/c^2$	1.64ps
B_d	$5.28\ \mathrm{GeV}/c^2$	1.51ps
B_c	$6.28\ \mathrm{GeV}/c^2$	0.51ps

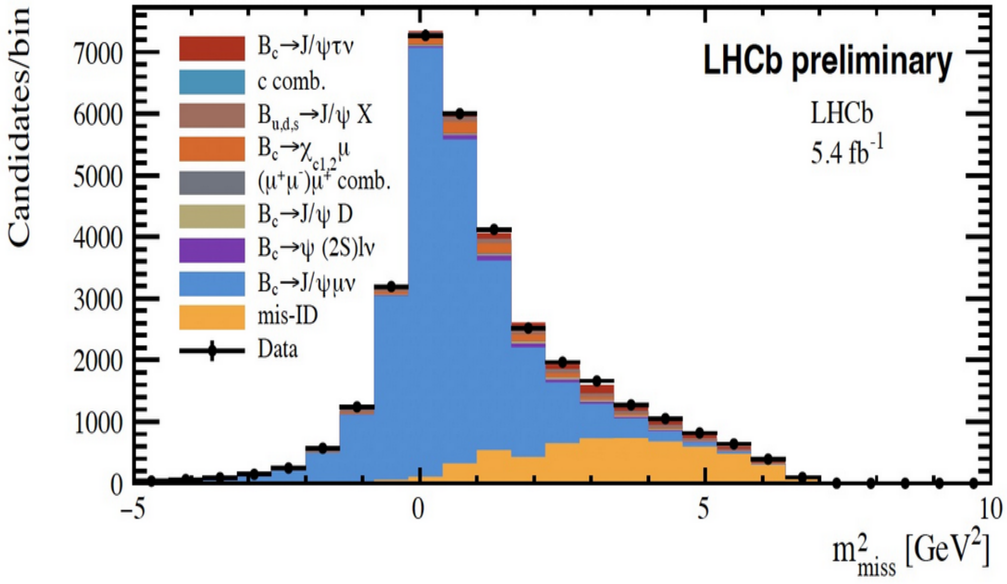
$B_c \to J/\psi\ \mu\ \nu$

- Golden channel at LHC: 3 muons in the final state
  - Used for many analysis: lifetime, production fraction, $R(J/\Psi)$, most of the known decay channels are normalized to $B_c \to J/\Psi\ \mu\ \nu$

PRD 100, 112006

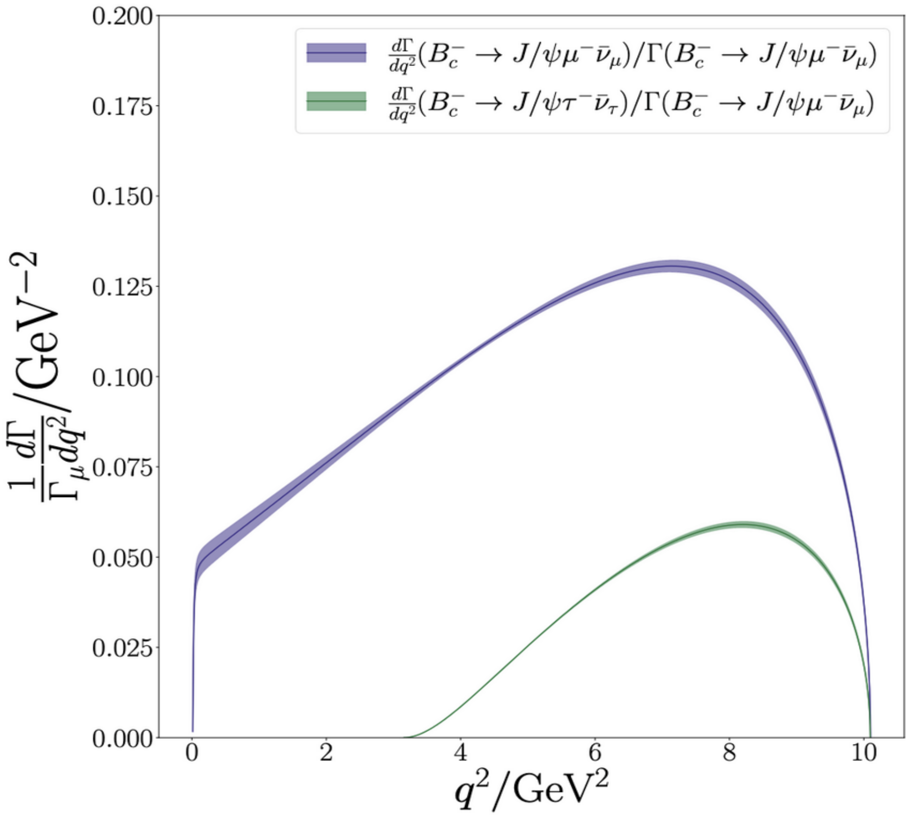


CERN seminar May 2026



$B_c \to J/\psi\ \mu\ \nu$ on L_QCD

HPQCD PRD 112 (2025) 3, 034503



Predicted BF:

$15.3 \pm 0.4_{\mathrm{LQCD}} \pm 0.6_{V_{cb}} \pm 0.3_{\tau}$

+

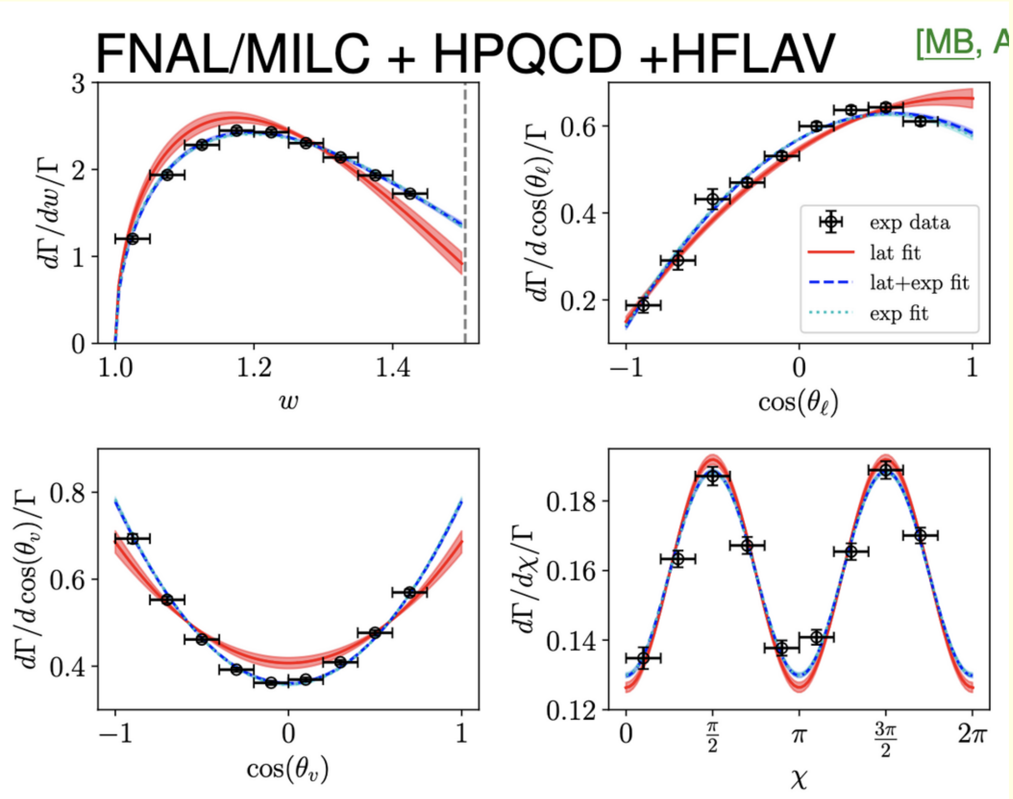
$$\frac{f_c}{f_u + f_d} \cdot \mathcal{B}(B_c^- \to J/\psi\mu^-\bar{\nu}) = (7.36 \pm 0.08 \pm 0.30) \times 10^{-5} \quad \text{for 13 TeV}$$

$$\frac{f_c}{f_d + f_u} = (4.81 \pm 0.20_{exp} \pm 0.24_{LQCD+ext.}) \cdot 10^{-3}$$

High precision on many observables of interest!

But…

B → D* l nu



Mandatory to study the differential rate for $B_c \to J/\Psi\ \tau\ \nu$

Extend study of differential q^2 spectrum and ratio of BFs, to other final states:

- $\Psi(2S)$: background in various analysis

- η_c ($\Phi\Phi$, $p\bar{p}$,…): fundamental state, but the cleanest η_c decay modes, BF~10^{-3}

- χ_{c1} ?
- $\chi_{c1} \leftrightarrow X(3872)$?

end

B_s semileptonic decays

- Complementary measurements to those from B^0 and B^+
- Advantages:
  - Lattice calculations easier due to heavier spectator quark, so predictions are more precise
  - For the $B_s \to D_s^*$: the *zero-width* approximation of the D_s^* is more valid than the B case (no $D\pi$ pollution)
  - Experimental point: different background composition from excited D_s states than in the $B \to D^*$ case

Golden modes for Lattice-QCD