CKM 2023, Working Group 2: Summary Talk

V_{ub}, V_{cb} and (semi-)leptonic B decays including τ

Svende Braun — Univ. Washington
William I. Jay — MIT
Raynette van Tonder — McGill
Ryoutaro Watanabe — CCNU

12th International Workshop on the CKM Unitarity Triangle
Santiago de Compostela, Spain
18-22 September 2022

The WG2 Program

24 talks, 4 days — Thanks to all the speakers for excellent presentations

Global fit to b-> c tau nu — *Syuhei Iguro*
Salón Peregrinos 17:15 - 17:39

Constrained 2nd-order power corrections in HQET — *Markus Tobias Prim*
Salón Peregrinos 17:39 - 18:03

LFU tests at Belle/Belle II — *Bob Kowalewski*
Salón Peregrinos 18:03 - 18:27

Impact of Lambdab -> Lambdac tau nu on new physics in b -> c tau nu transitions — *Marco Fedele*
Salón Peregrinos 18:27 - 18:51

LFU tests in semileptonic decays at LHCb — *Marta Calvi*
Salón Peregrinos 18:51 - 19:15

Updates on inclusive charmed and bottomed meson decays from lattice — *Ryan Kellermann*
Salón Peregrinos 11:30 - 12:00

HQE in inclusive SL decays — *Keri Vos et al.*
Salón Peregrinos 12:00 - 12:30

Recent measurements of inclusive SL decays at the beauty and charm factories — *Markus Tobias Prim*
Salón Peregrinos 12:30 - 13:00

Exclusive SL B-decays at Belle/Belle II — *Christoph Schwanda*
Salón Peregrinos 17:15 - 17:39

CKM matrix elements at LHCb — *Blaise Raheem Delaney*
Salón Peregrinos 17:39 - 18:03

B(s)->D^(*)(s) from FNAL/MILC — *Alejandro Marino Vaquero Avilés-Casco*
Salón Peregrinos 18:03 - 18:27

Model independent description of B -> D pi l nu decays — *Florian Herren*
Salón Peregrinos 18:27 - 18:51

Extraction of the ratio $|V_{ub}|/|V_{cb}|$ from the combined study of the exclusive decays — *IPSITA RAY*
Salón Peregrinos 18:51 - 19:15

Unitarity constraints and the dispersive matrix — *Ludovico VITTORIO*
Salón Peregrinos 09:00 - 09:24

Combining lattice and sum rules to determine |Vub|/|Vcb| — *Carolina Da Silva Bolognani*
Salón Peregrinos 09:24 - 09:48

NLO QCD corrections for B -> Xc tau nu — *Daniel Moreno*
Salón Peregrinos 09:48 - 10:12

New physics contributions to moments of incl. b -> c — *Matteo Fael*
Salón Peregrinos 10:12 - 10:36

|Vub| and the potential impact of new physics in exclusive b -> u l nu decays — *Blaženka Melić*
Salón Peregrinos 10:36 - 11:00

Recent CMS results on flavor anomalies and lepton flavor violation — *Riccardo Manzoni*
Salón Peregrinos 09:00 - 09:24

LHCb prospects on semileptonic decays — *Marcello Rotondo*
Salón Peregrinos 09:24 - 09:48

Recent results on leptonic/rare decays at Belle/Belle II — *Justine Serrano*
Salón Peregrinos 17:20 - 17:50

Lattice outlook on B->rho and B->K* — *Luka Leskovec*
Salón Peregrinos 17:50 - 18:20

Rare B->pi and B->K decays on the lattice — *Dr Chris Bouchard*
Salón Peregrinos 18:20 - 18:50

B->pi, B ->D(*) from JLQCD — *Dr Brian Colquhoun*
Salón Peregrinos 18:50 - 19:20

Outline

- Experimental measurements
  - Lepton Flavor Universality ratio (measurements)
  - Semileptonic decays and CKM metrology (measurements)
- Theory
  - Lattice QCD
  - Heavy quark effective theory
- Combined analyses

Disclaimer:
I’m still absorbing the results/ideas from the many nice presentations.

Apologies for any omissions or mischaracterizations.

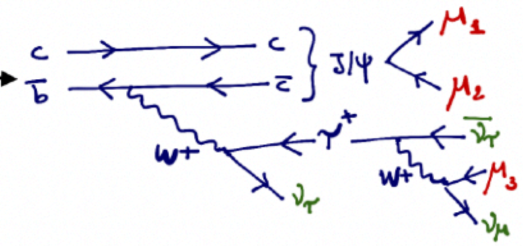
Apologies for missing/incomplete citations — please see the talks!

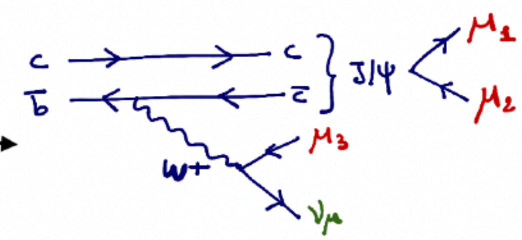
Lepton Flavor Universality (Experimental Measurements)

Recent results on flavour anomalies and lepton flavour (universality) violation at CMS

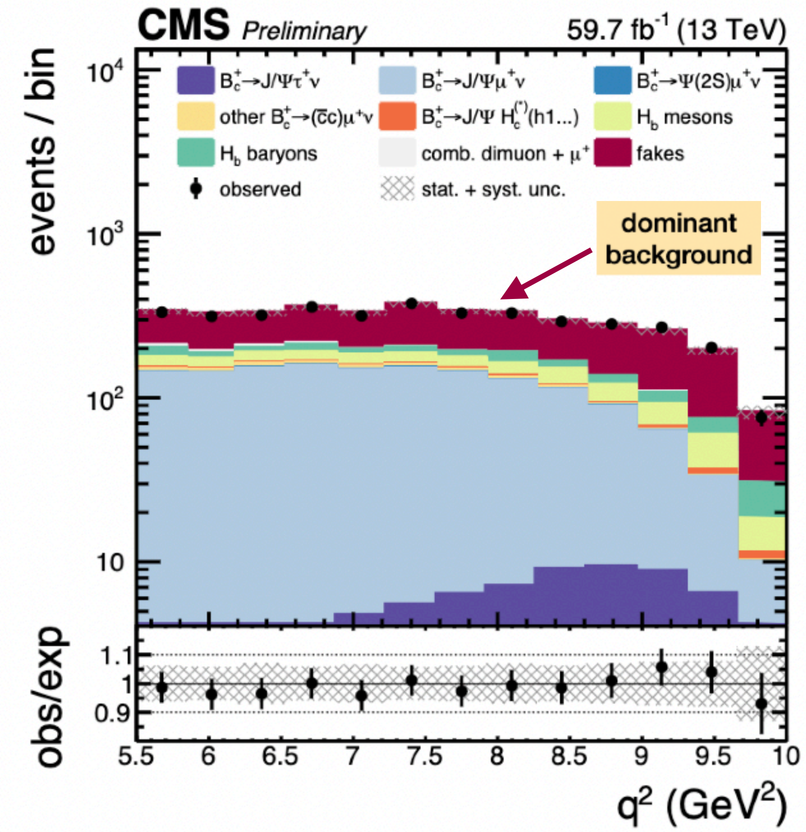
Riccardo Manzoni

$$R(J/\psi) = \frac{\mathscr{B}(B_c \to J/\psi\,\tau\,\nu_\tau)}{\mathscr{B}(B_c \to J/\psi\,\mu\,\nu_\mu)}$$

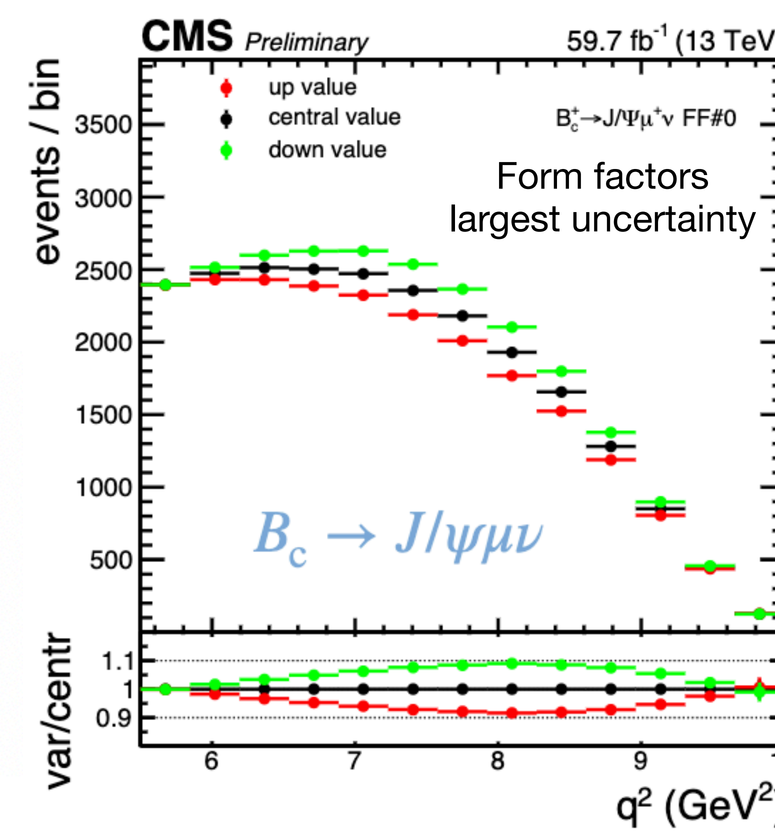




$$p_{B_c} = m_{B_c}^{\mathrm{PDG}} / m_{3\mu}^{\mathrm{vis}} \cdot p_{3\mu}^{\mathrm{vis}}$$



$$R(J/\psi) = 0.17\,^{+0.18}_{-0.17}\,(\mathrm{stat.})\,^{+0.19}_{-0.19}\,(\mathrm{theo.})\,^{+0.21}_{-0.22}\,(\mathrm{syst.})$$



- **first LFUV result in $b \to c\ell\nu$ transitions at CMS**
  on partial Run2 dataset
- in agreement with both SM 0.26 and LHCb 0.17 ± 0.25 within less than 1σ
- **sensitivity expected to significantly improve in coming iterations**

LFU tests in semileptonic decays at LHCb

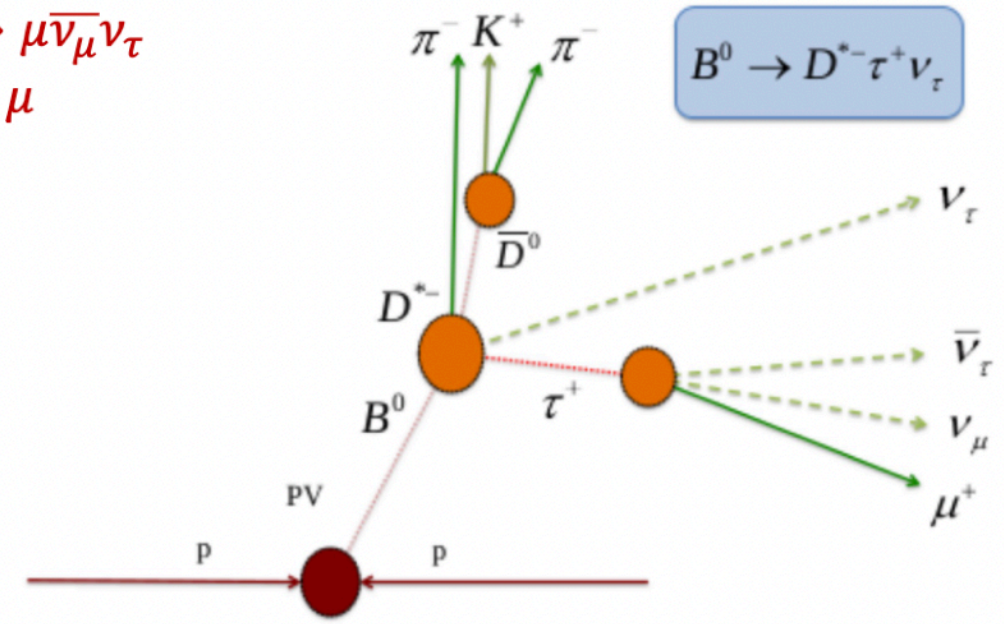
Marta Calvi

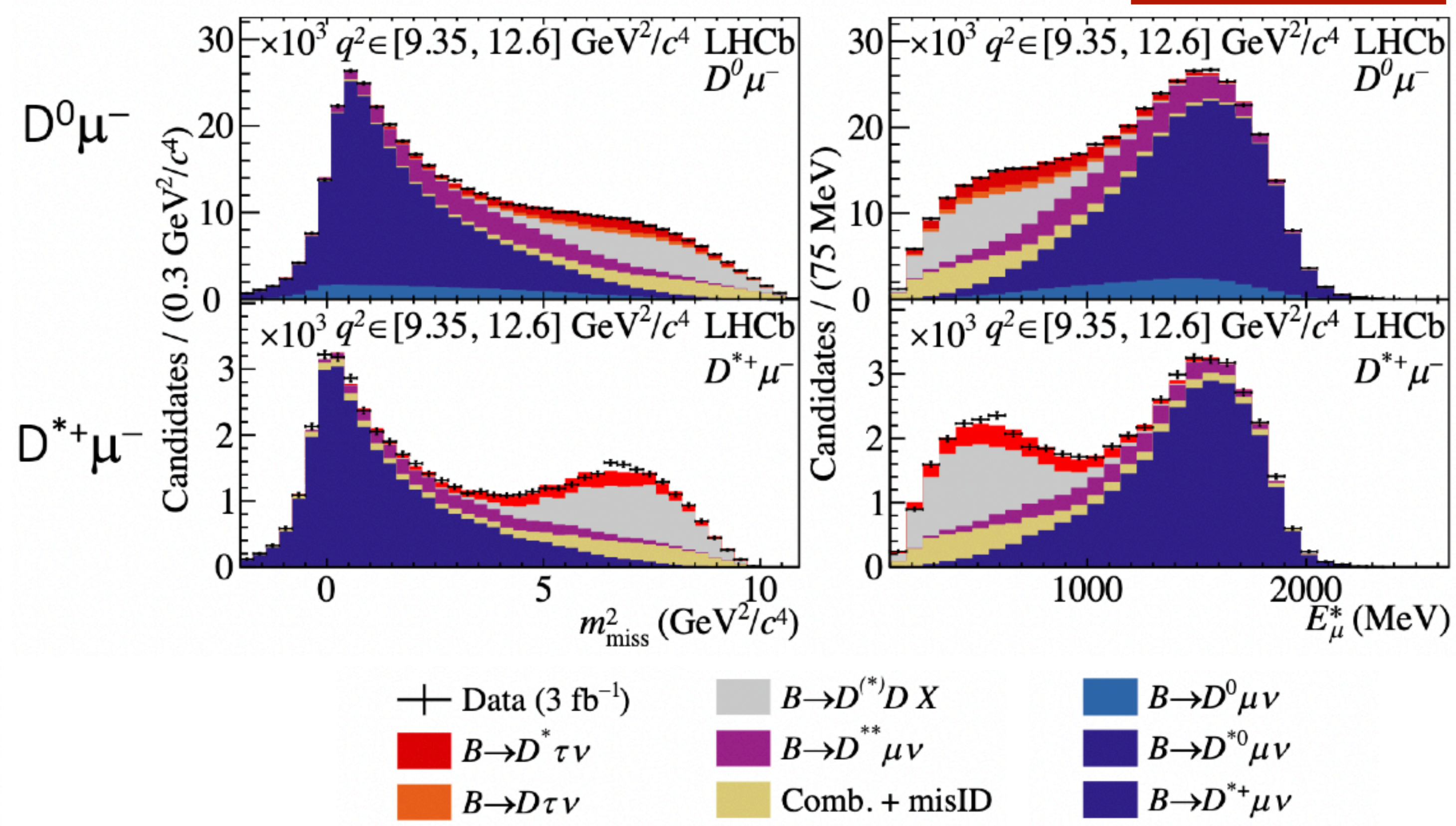
Run1 data set

Muonic tau decay

$\tau \rightarrow \mu \overline{\nu_\mu} \nu_\tau$

$\ell = \mu$





- Higher branching fraction and higher efficiency for the $D^0\mu^-$ sample
  - Veto $D^{*+} \rightarrow D^0\pi^+$ in the $D^0\mu^-$ sample (exclusive samples)
- Use rest-frame quantities to distinguish signal in 3D fits: $m^2_{missing}$, E_μ, $q^2 = (p_B - p_D)^2$

$R(D^*) = 0.281 \pm 0.018(stat) \pm 0.024(syst)$

$R(D^0) = 0.441 \pm 0.060(stat) \pm 0.066(syst)$ $\rho = -0.43$

- In agreement with $R(D^*)$-$R(D)$ world-average, 1.9 σ above the SM prediction.
- Main systematic uncertainties: limited size of simulated sample and effect of shape parameters derived from control regions.

LEPTON FLAVOR UNIVERSALITY AT BELLE (II)

Bob Kowalewski

$$R_{\tau/\ell}(D^*) \propto \frac{N(B \to D^*[\tau \to \ell\bar{\nu}\nu]\nu)}{N(B \to D^*\ell\nu)}$$

- Distinguish $\bar{B} \to D^*\tau^- \nu$ from $\bar{B} \to D^*\ell^- \nu$ and background using M^2_{miss}, require no unused charged particles and small *unassigned neutral ECL energy* (E_{ECL})
- Determine yields with a 2D binned template likelihood fit

Main sources of systematic uncertainty:

- MC statistics ± 7.0 %
- E_{ECL} PDF shapes $^{+5.5}_{-9.3}$ %
- D^{**} modeling $^{+4.7}_{-2.7}$ %

Belle II preliminary: first result on this channel

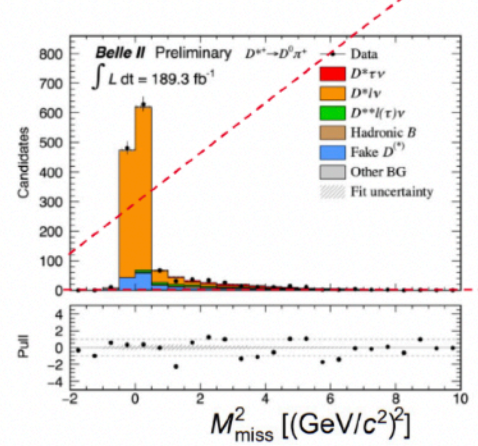
$$R(D^*) = 0.267\ ^{+0.041}_{-0.039}(\text{stat})\ ^{+0.028}_{-0.033}(\text{sys})$$

Consistent with SM,

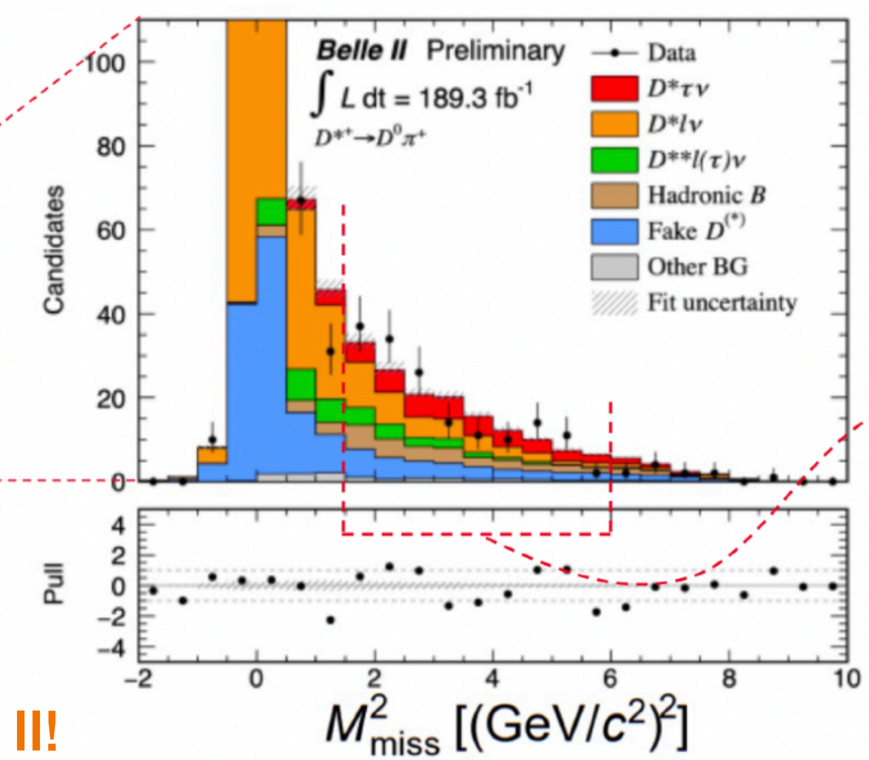
$R(D^*) = 0.254 \pm 0.005$

and with HFLAV 23,

$R(D^*) = 0.284 \pm 0.013$

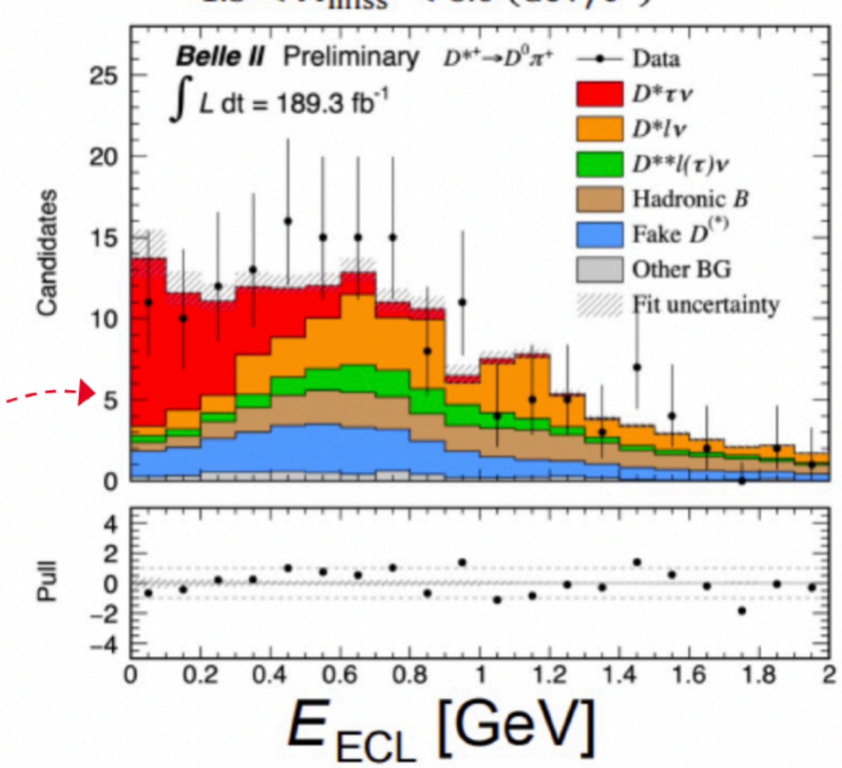


Zoom of M^2_{miss} projection for $D^{*+} \to D^0\pi^+$ mode



Signal-enhanced projection for $D^{*+} \to D^0\pi^+$ mode

$1.5 < M^2_{\text{miss}} < 6.0\ (\text{GeV}/c^2)^2$



First $R(D^*)$ measurement from Belle II!

LEPTON FLAVOR UNIVERSALITY AT BELLE (II)

Bob Kowalewski

$$R_{\tau/\ell}(X) \propto \frac{N(B \to X[\tau \to \ell\bar{\nu}\nu]\nu)}{N(B \to X\ell\nu)}$$

- Distinguish $\bar{B} \to X\tau^- \nu$ from $\bar{B} \to X\ell^- \nu$ and background using M^2_{miss} and *kinematics* (p^*_ℓ) (but *not* E_{ECL})
- Background mostly from $b \to c \to \ell$; some continuum, fakes
- Detailed corrections based on comparisons of simulation with control regions: low q^2 ($X_c\ell\nu$), low $M^2_{\text{miss}}(X_c\ell\nu)$, high M_X (background)

First $R_{\tau/\ell}(X)$ result at $\Upsilon(4S)$ **(Belle II preliminary)**

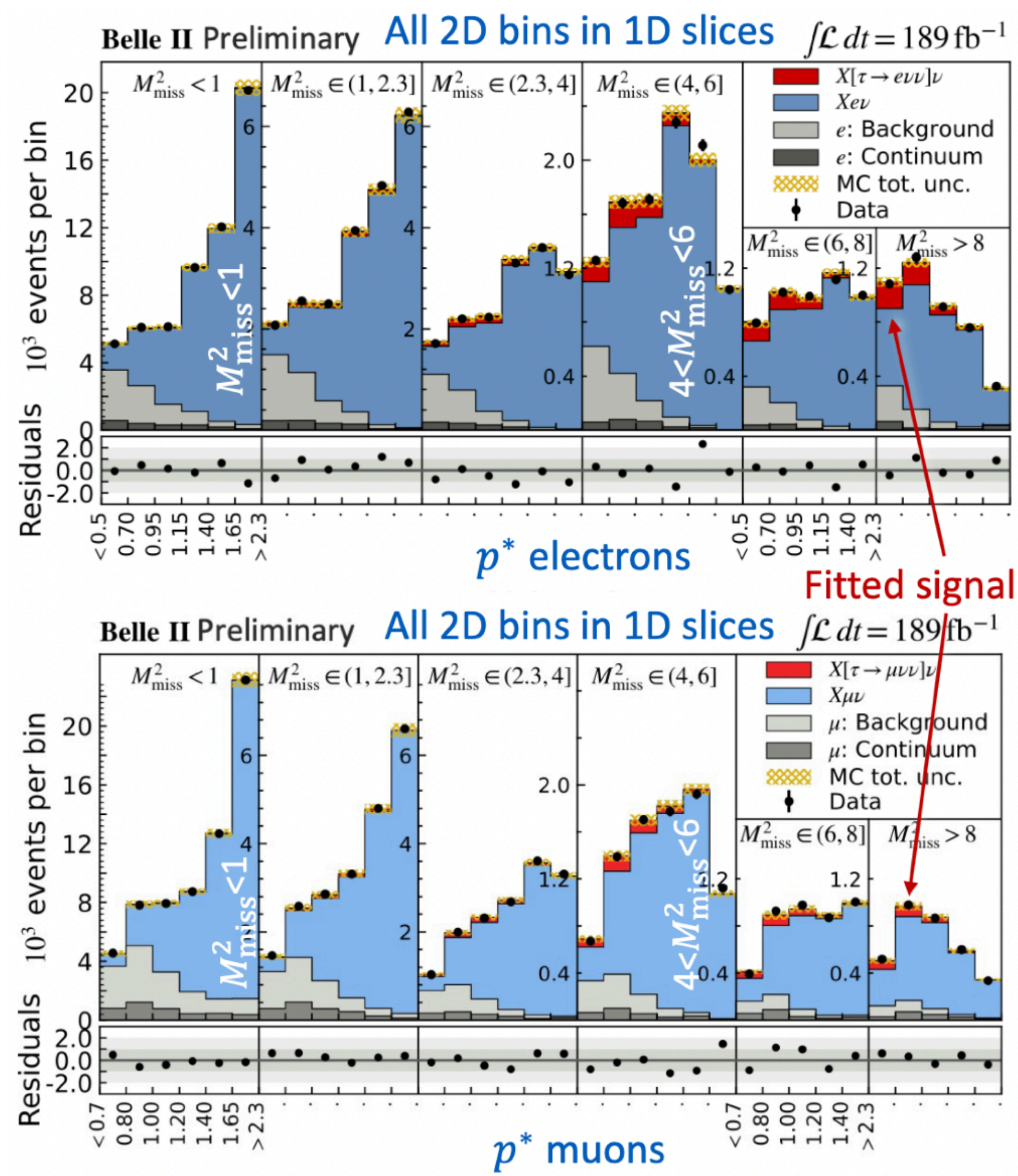
$$R_{\tau/\ell}(X) = 0.228 \pm 0.016(\text{stat}) \pm 0.036\ (\text{sys})$$

$$R_{\tau/e}(X) = 0.232 \pm 0.020(\text{stat}) \pm 0.037\ (\text{sys})$$

$$R_{\tau/\mu}(X) = 0.222 \pm 0.027(\text{stat}) \pm 0.050\ (\text{sys})$$

Main sources of systematic uncertainty:

- MC stat ±5.7 %
- Bkg shape ±5.5 %
- M_X modeling ±7.1 %
- $B \to X_c\ell\nu$ BFs ±7.7 %
- $B \to X_c\ell\nu$ FFs ±7.9 %



Compatible with SM value: $R_{\tau/\ell}(X)$ = 0.223 ± 0.004

K.Vos & M. Rahimi: arXiv:2207.03432

Semileptonic Decays
& CKM Metrology
(Experimental Measurements)

Recent measurements of inclusive SL decays

Markus Prim - Belle

- Gain insights on the inclusive-exclusive V_{ub} puzzle with combined analysis
- Extract signal in bins of q^2 and N_π for $B \to \pi \ell \nu$ and other $B \to X_u \ell \nu$
- Trade-off: large individual uncertainties on either incl. or excl. V_{ub}

$$\mathcal{B}(B \to \pi^0 \ell \nu) + \mathcal{B}(B \to \pi^+ \ell \nu) + \mathcal{B}(B \to X_u^{\text{other}} \ell \nu) = \mathcal{B}(B \to X_u \ell \nu)$$

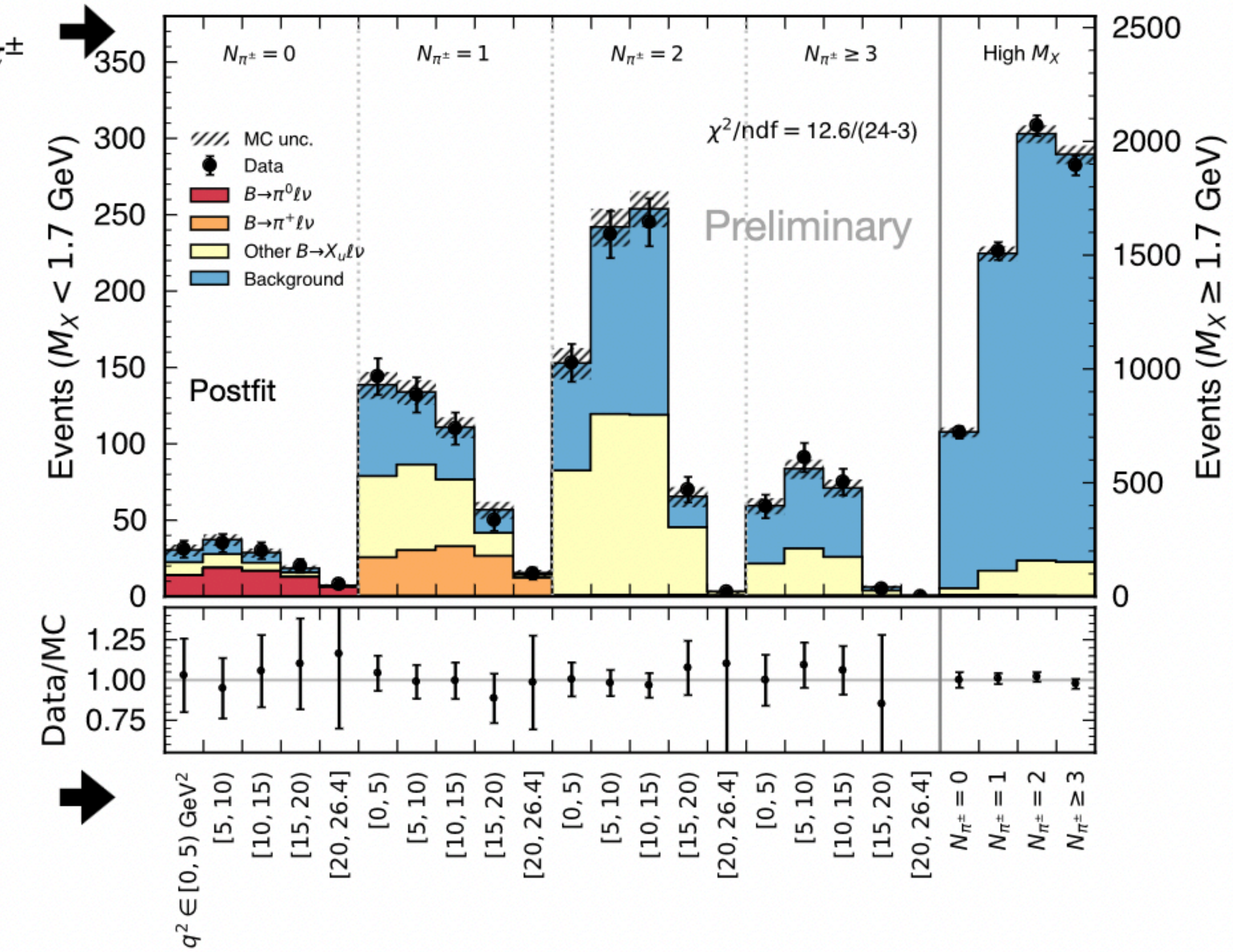
$$|V_{ub}^{\text{excl.}}| = \sqrt{\frac{\mathcal{B}(B \to \pi \ell \nu)}{\tau_B \cdot \Gamma_{\text{FF}}}}$$

$$\Delta\mathcal{B}(B \to X_u \ell \nu) = \mathcal{B}(B \to X_u \ell \nu) \cdot \epsilon_{\Delta \text{PS}: E_\ell^B > 1 \text{GeV}}$$

$$|V_{ub}^{\text{incl.}}| = \sqrt{\frac{\Delta\mathcal{B}(B \to X_u \ell \nu)}{\tau_B \cdot \Delta\Gamma_{\text{GGOU}}}}$$

$N_{\pi^\pm}$ →

q^2 →

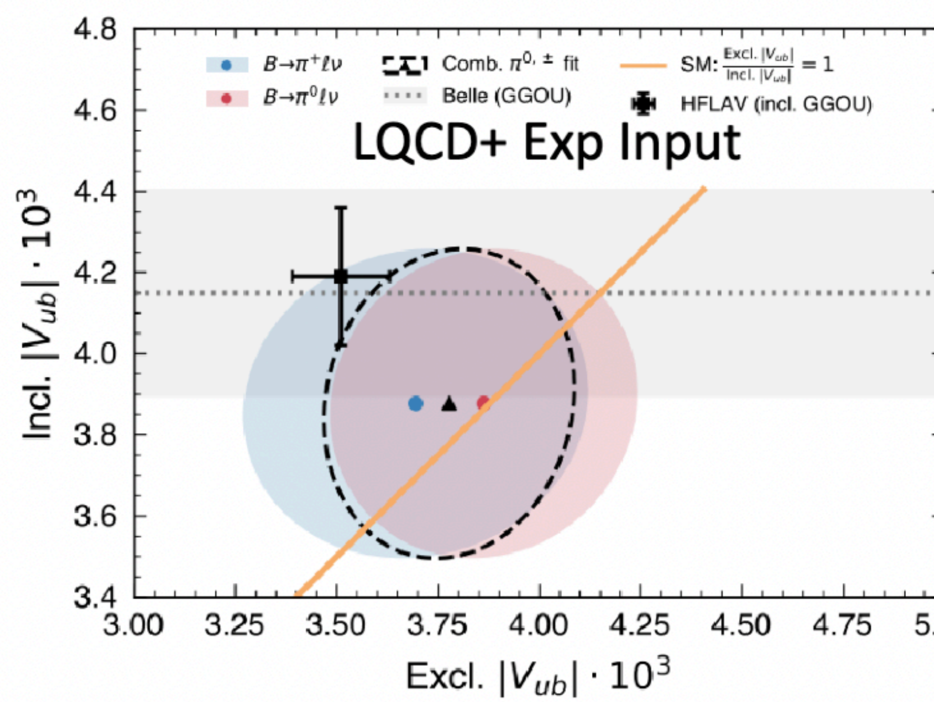


|V$_{ub}$| in **combined** scenario with **LQCD+exp** const.:

Excl. $(3.78 \pm 0.23_{\text{stat}} \pm 0.16_{\text{syst}} \pm 0.14_{\text{theo}}) \times 10^{-3}$

Incl. $(3.88 \pm 0.20_{\text{stat}} \pm 0.31_{\text{syst}} \pm 0.09_{\text{theo}}) \times 10^{-3}$

Ratio $0.97 \pm 0.12 \quad (\rho = 0.11)$ compatible with the world average within 1.2σ



CKM metrology with semileptonic B decays at LHCb

Blaise Delaney

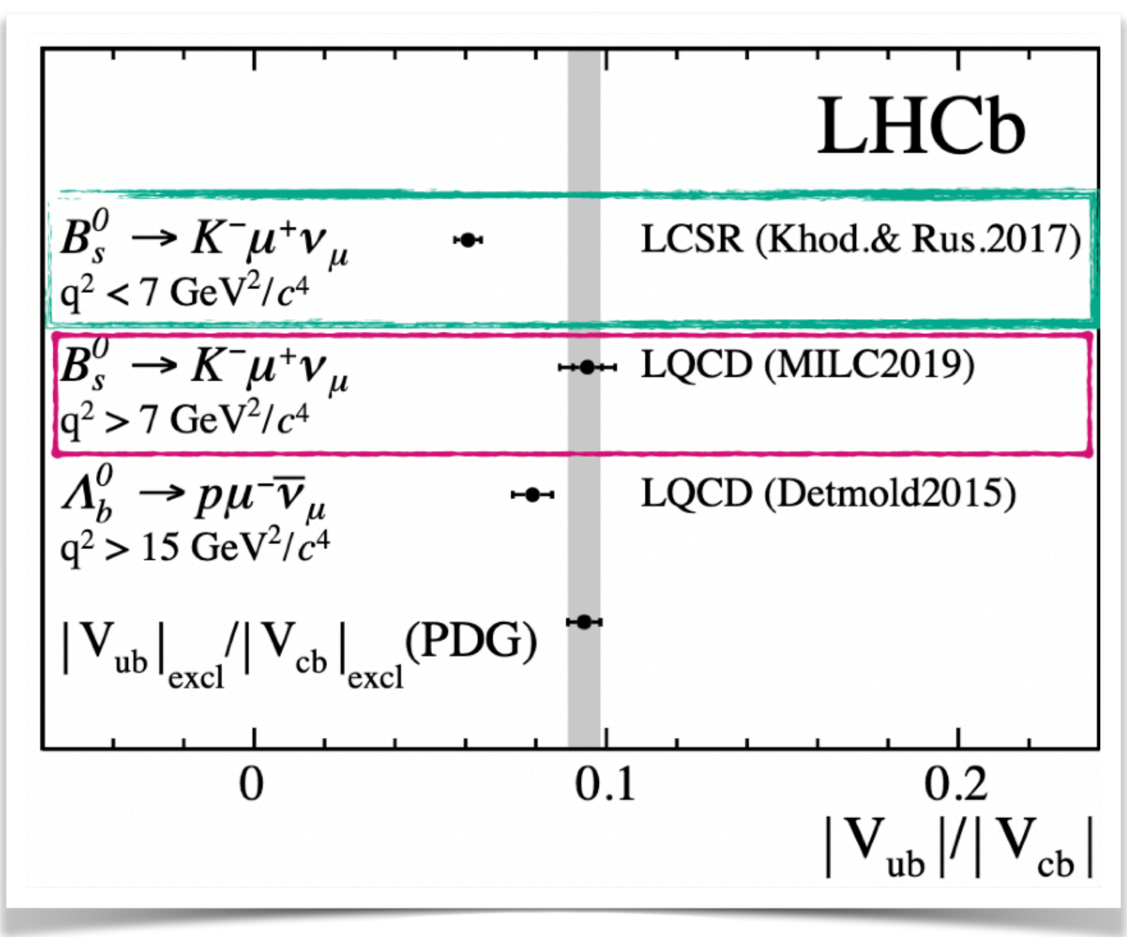
$$\frac{|V_{ub}|^2}{|V_{cb}|^2} \times \overbrace{\frac{\mathrm{FF}_K}{\mathrm{FF}_{D_s}}}^{\text{Theory input}} = \overbrace{\frac{\mathcal{B}(B_s^0 \to K^-\mu^+\nu_\mu)}{\mathcal{B}(B_s^0 \to D_s^-\mu^+\nu_\mu)}}^{\text{Experiment}} = \underbrace{\frac{N_K}{N_{D_s}}}_{\text{Fit}} \; \underbrace{\frac{\varepsilon_{D_s}}{\varepsilon_K}}_{\text{Simulation}} \times \underbrace{\mathcal{B}(D_s^+ \to K^+K^-\pi^+)}_{\text{PTEP 2020 (2020) 8, 083C01}}$$

$|V_{ub}|/|V_{cb}|$ extraction in **two regions of q^2 using FF$_K$ calculations**

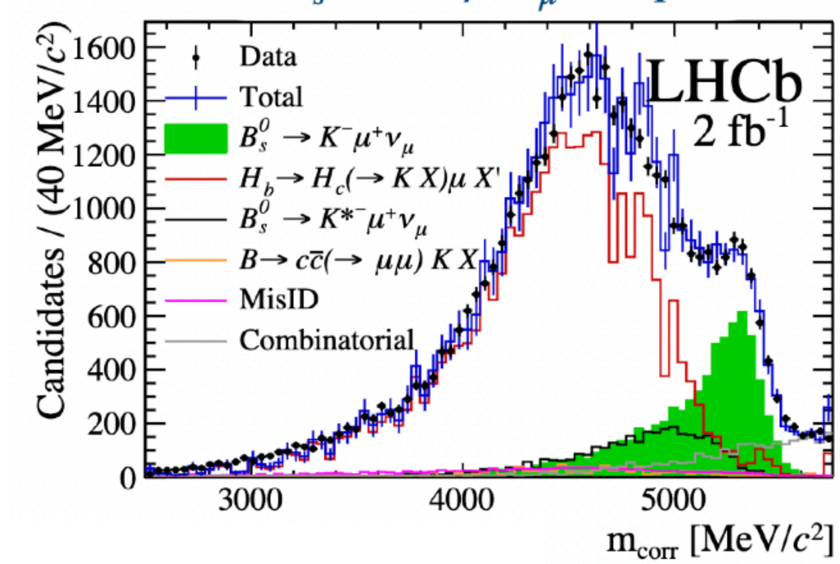
a) LCSR @ $q^2 < 7$ GeV²/c⁴ [JHEP 2017, 112 (2017)]
b) Lattice QCD @ $q^2 > 7$ GeV²/c⁴ [Phys. Rev. D 100, 034501]

Low q^2: $$\frac{\mathcal{B}(B_s^0 \to K^-\mu^+\nu_\mu)}{\mathcal{B}(B_s^0 \to D_s^-\mu^+\nu_\mu)} = 1.66 \pm 0.08(\mathrm{stat}) \pm 0.07(\mathrm{syst}) \pm 0.05(D_s) \times 10^{-3}$$

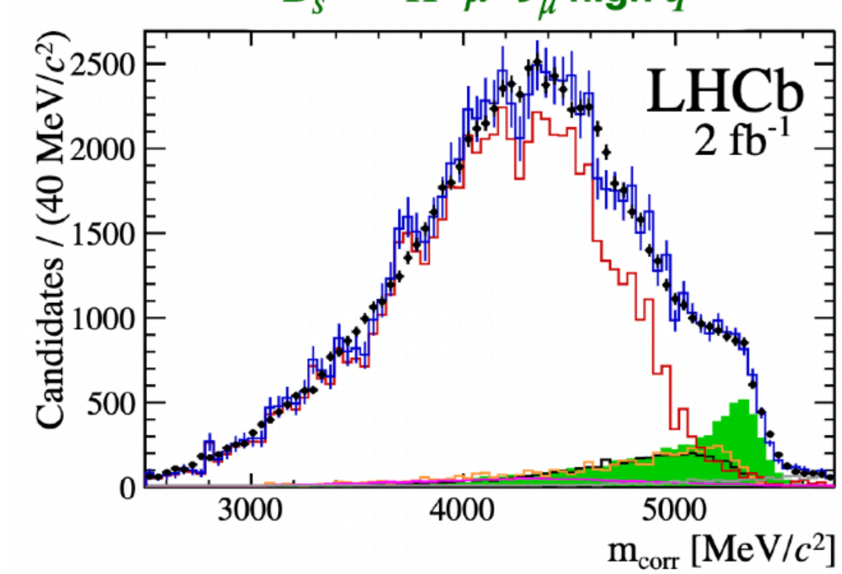
High q^2: $$\frac{\mathcal{B}(B_s^0 \to K^-\mu^+\nu_\mu)}{\mathcal{B}(B_s^0 \to D_s^-\mu^+\nu_\mu)} = 3.25 \pm 0.21(\mathrm{stat})^{+0.16}_{-0.17}(\mathrm{syst}) \pm 0.09(D_s) \times 10^{-3}$$



$B_s^0 \to K^-\mu^+\nu_\mu$ **low** q^2



$B_s^0 \to K^-\mu^+\nu_\mu$ **high** q^2

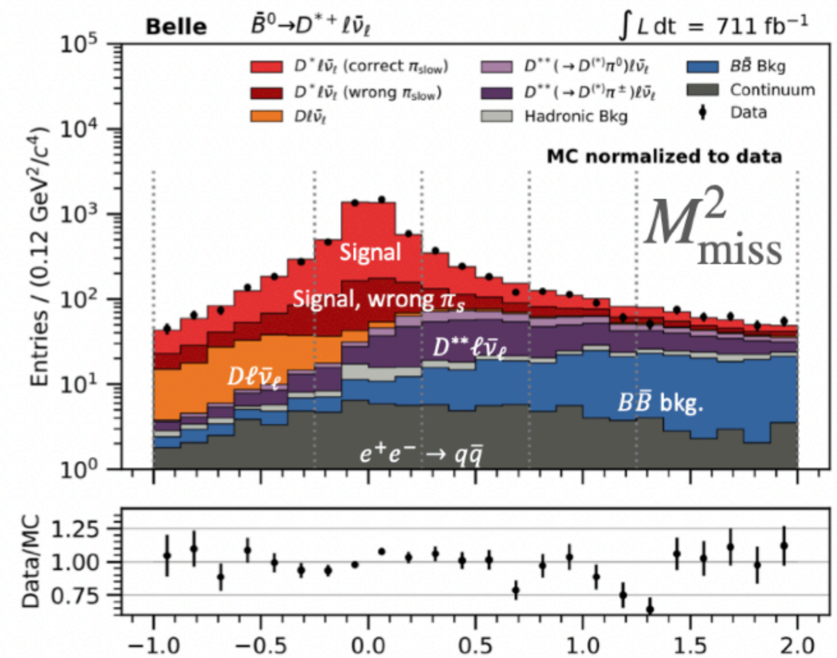


Exclusive semileptonic B decays at Belle (II)

Christoph Schwanda

- Measure 12 angular coefficients J_i in bins of w
- Look for LFU violation using $\Delta J_i \equiv J_i^{\mu} - J_i^{e}$

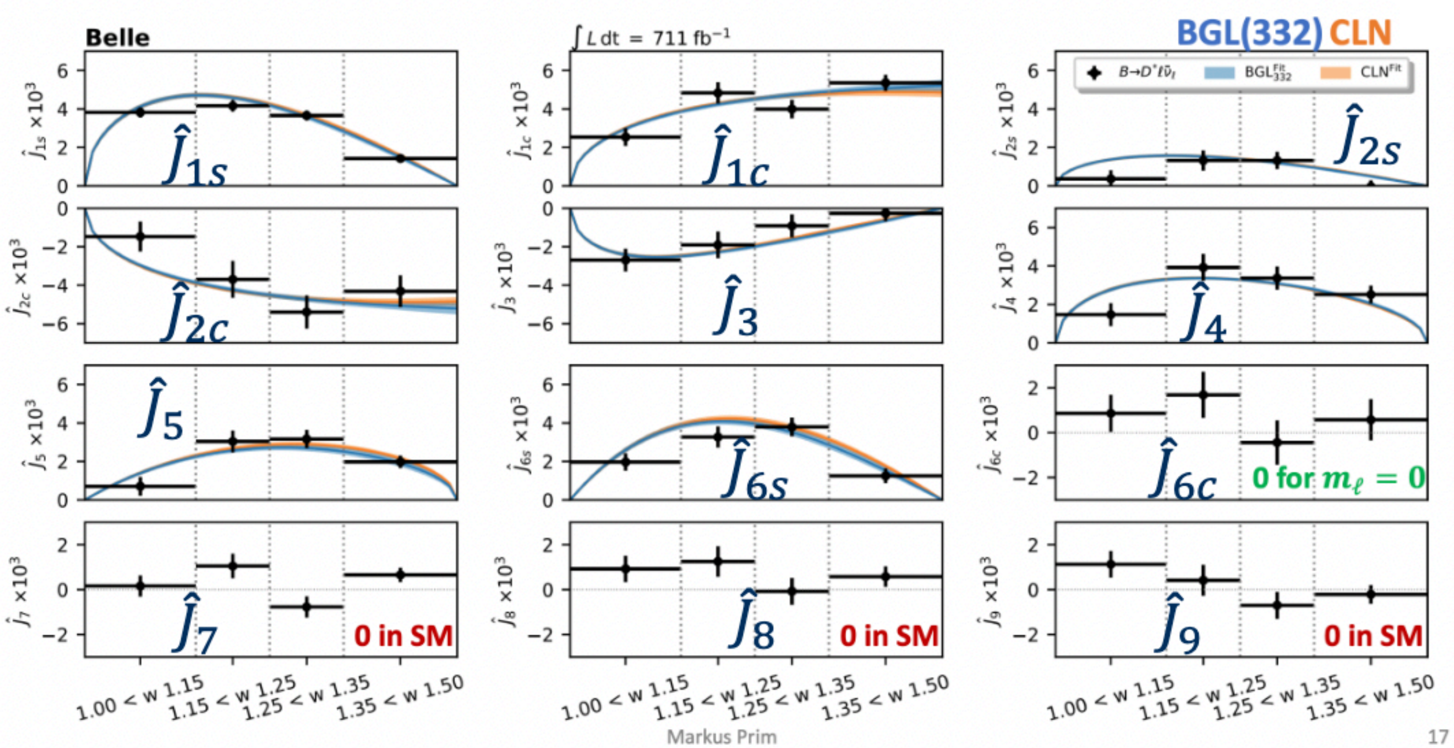
$$\frac{\mathrm{d}\Gamma(B \to D^*\ell\nu_\ell)}{\mathrm{d}w\mathrm{d}\cos\theta_\ell\mathrm{d}\cos\theta_V\mathrm{d}\chi} = \frac{2G_F^2\eta_{EW}^2|V_{cb}|^2 m_B^4 m_{D^*}}{2\pi^4} \times \Big(J_{1s}\sin^2\theta_V + J_{1c}\cos^2\theta_V + (J_{2s}\sin^2\theta_V + J_{2c}\cos^2\theta_V)\cos 2\theta_\ell + J_3\sin^2\theta_V\sin^2\theta_\ell\cos 2\chi + J_4\sin 2\theta_V\sin 2\theta_\ell\cos\chi + J_5\sin 2\theta_V\sin\theta_\ell\cos\chi + (J_{6s}\sin^2\theta_V + J_{6c}\cos^2\theta_V)\cos\theta_\ell + J_7\sin 2\theta_V\sin\theta_\ell\sin\chi + J_8\sin 2\theta_V\sin 2\theta_\ell\sin\chi + J_9\sin^2\theta_V\sin^2\theta_\ell\sin 2\chi\Big).$$



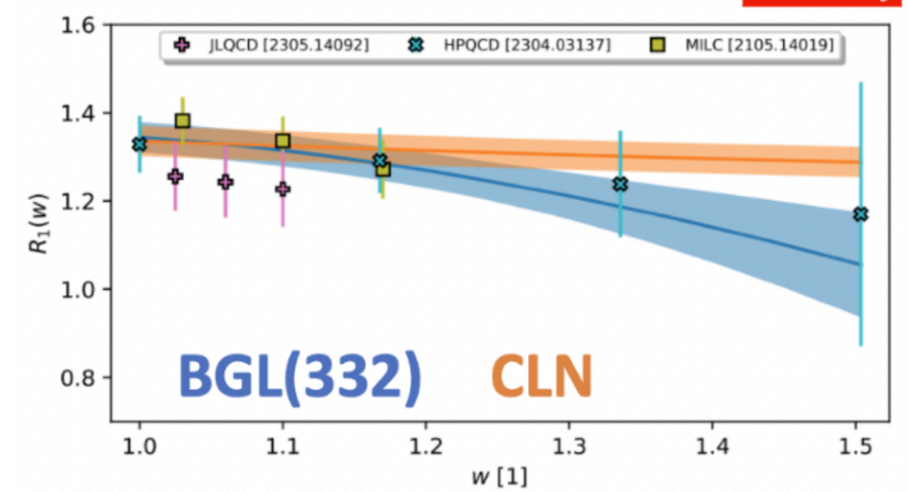
Extraction Method: Missing Mass Squared

$$0 = m_\nu^2 = M^2_{miss} = (p_{e^+e^-} - p_B - p_{D^*} - p_\ell)^2$$

Angular Coefficients of $B \to D^*\ell\bar{\nu}_\ell$ vs. w

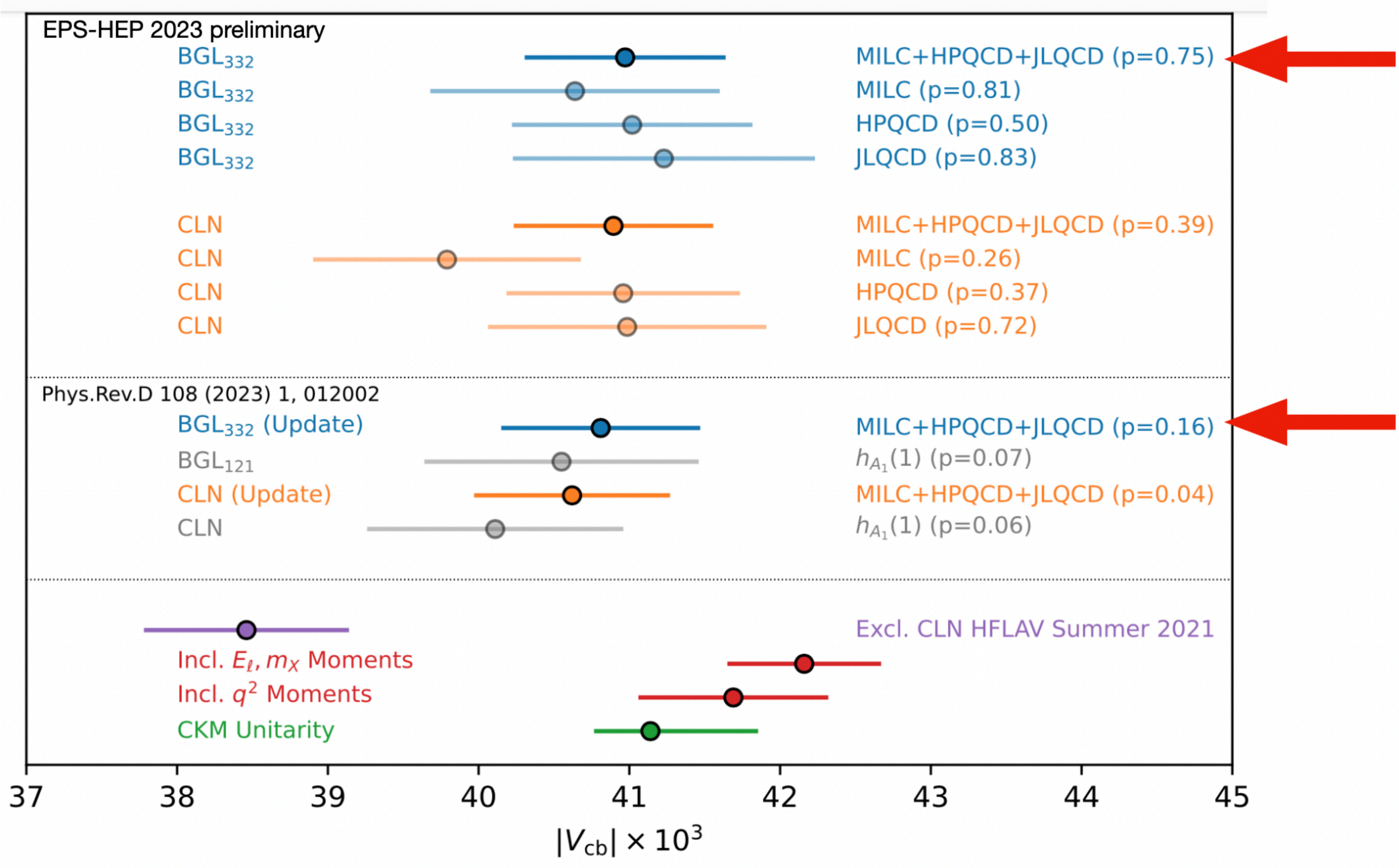


Preliminary



$|V_{cb}|^{BGL} = (41.0 \pm 0.7) \times 10^{-3}$

$|V_{cb}|^{CLN} = (40.9 \pm 0.7) \times 10^{-3}$



EPS-HEP 2023 preliminary
BGL332
MILC+HPQCD+JLQCD (p=0.75)
BGL332
MILC (p=0.81)
BGL332
HPQCD (p=0.50)
BGL332
JLQCD (p=0.83)
CLN
MILC+HPQCD+JLQCD (p=0.39)
CLN
MILC (p=0.26)
CLN
HPQCD (p=0.37)
CLN
JLQCD (p=0.72)
Phys.Rev.D 108 (2023) 1, 012002
BGL332 (Update)
MILC+HPQCD+JLQCD (p=0.16)
BGL121
hA1(1) (p=0.07)
CLN (Update)
MILC+HPQCD+JLQCD (p=0.04)
CLN
hA1(1) (p=0.06)
Excl. CLN HFLAV Summer 2021
Incl. Eℓ, mX Moments
Incl. q2 Moments
CKM Unitarity
37
38
39
40
41
42
43
44
45
|Vcb| × 10^3

Exclusive semileptonic B decays at Belle (II)

Christoph Schwanda

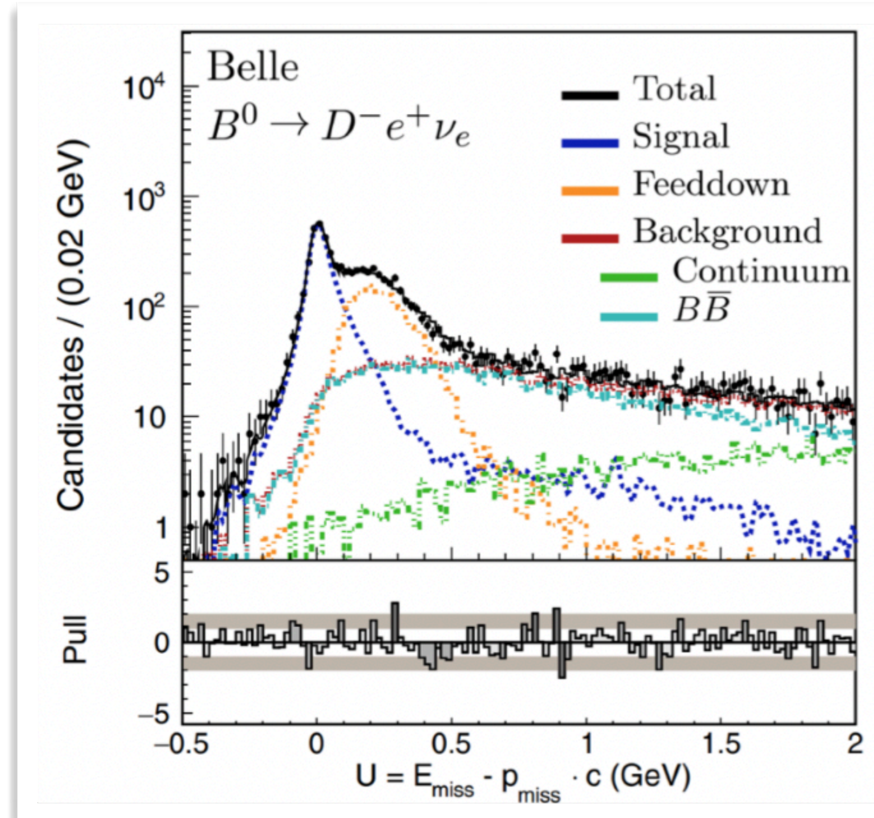
- Use full Belle dataset and reconstruct 16 final states:

  $\bar{D}^0\pi^-, D^-\pi^+, \bar{D}^{*0}\pi^-, D^{*-}\pi^+, D^-\pi^+\pi^-, \bar{D}^0\pi^+\pi^-, D^{*-}\pi^+\pi^-, D^{*0}\pi^+\pi^-\ell^+\nu$

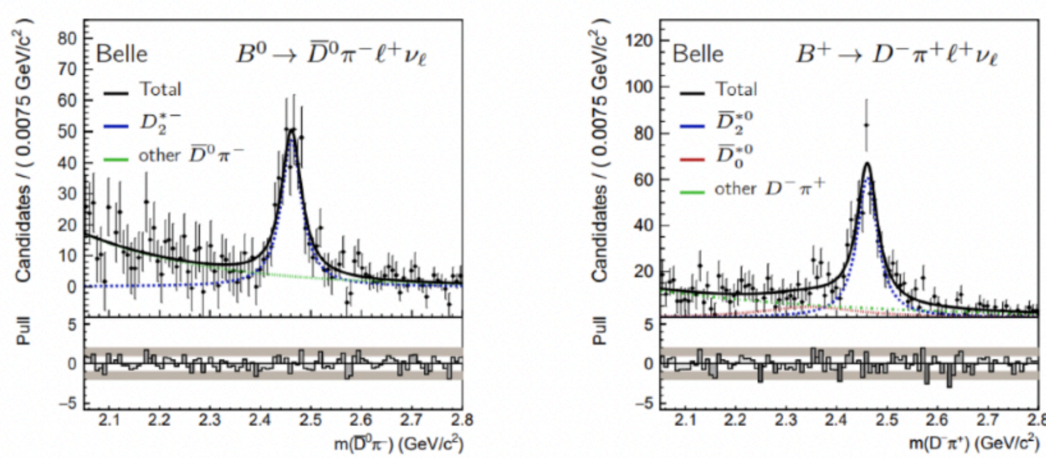
  with $\ell = e, \mu$

- Normalisation modes: $B^0 \to D^{*-}\ell^+\nu$ and $B^+ \to \bar{D}^{*0}\ell^+\nu$

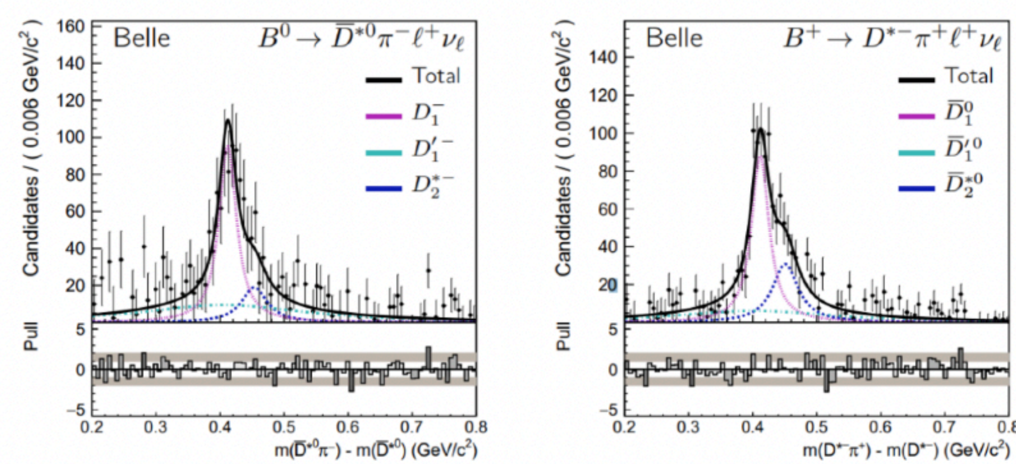
- Signal extracted from $U = E_{\rm miss} - p_{\rm miss}$



$M(D\pi)$



$M(D^*\pi)$



	yield	branching fraction [%]	PDG [%]
$B^0 \to D_0^{*-}\ell^+\nu_\ell$ with $D_0^{*-} \to \bar{D}^0\pi^-$	-	<0.044 at 90% CL	0.30 ± 0.12
$B^0 \to D_2^{*-}\ell^+\nu_\ell$ with $D_2^{*-} \to \bar{D}^0\pi^-$	457±45	$0.157 \pm 0.015\,(\text{stat}) \pm 0.005\,(\text{syst})$	0.121 ± 0.033
other $B^0 \to \bar{D}^0\pi^-\ell^+\nu_\ell$	547±45	-	
$B^+ \to \bar{D}_0^{*0}\ell^+\nu_\ell$ with $\bar{D}_0^{*0} \to D^-\pi^+$	180±72	$0.054 \pm 0.022\,(\text{stat}) \pm 0.005\,(\text{syst})$	0.25 ± 0.05
$B^+ \to \bar{D}_2^{*0}\ell^+\nu_\ell$ with $\bar{D}_2^{*0} \to D^-\pi^+$	590±39	$0.163 \pm 0.011\,(\text{stat}) \pm 0.008\,(\text{syst})$	0.153 ± 0.016
other $B^+ \to D^-\pi^+\ell^+\nu_\ell$	520±70	-	

	yield	branching fraction [%]	PDG [%]
$B^0 \to D_1^-\ell^+\nu_\ell$ with $D_1^- \to \bar{D}^{*0}\pi^-$	866± 142	$0.306 \pm 0.050\,(\text{stat}) \pm 0.029\,(\text{syst})$	0.280 ± 0.028
$B^0 \to D_1'^-\ell^+\nu_\ell$ with $D_1'^- \to \bar{D}^{*0}\pi^-$	523± 173	$0.206 \pm 0.068\,(\text{stat}) \pm 0.025\,(\text{syst})$	0.31 ± 0.09
$B^0 \to D_2^{*-}\ell^+\nu_\ell$ with $D_2^{*-} \to \bar{D}^{*0}\pi^-$	145± 114	$0.051 \pm 0.040\,(\text{stat}) \pm 0.010\,(\text{syst})$	0.068 ± 0.012
$B^+ \to \bar{D}_1^0\ell^+\nu_\ell$ with $\bar{D}_1^0 \to D^{*-}\pi^+$	698 ± 65	$0.249 \pm 0.023\,(\text{stat}) \pm 0.015\,(\text{syst})$	0.303 ± 0.020
$B^+ \to \bar{D}_1'^0\ell^+\nu_\ell$ with $\bar{D}_1'^0 \to D^{*-}\pi^+$	353 ± 93	$0.138 \pm 0.036\,(\text{stat}) \pm 0.009\,(\text{syst})$	0.27 ± 0.06
$B^+ \to \bar{D}_2^{*0}\ell^+\nu_\ell$ with $\bar{D}_2^{*0} \to D^{*-}\pi^+$	382 ± 74	$0.137 \pm 0.026\,(\text{stat}) \pm 0.009\,(\text{syst})$	0.101 ± 0.024

Results agree well with PDG average, except only bounds were set for D_0^*

LHCb prospects on semileptonic decays

Marcello Rotondo

Beyond R(H$_c$): going differential

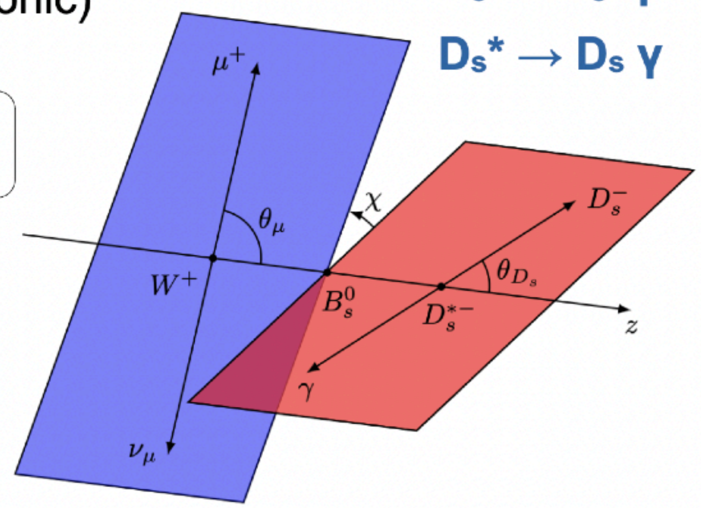
- Angular analyses with semitauonic (and semimuonic) to probe spin structure of physics beyond SM
  - Even in case R(H$_c$) is SM-like, it will put strong constraints on NP models

$$\frac{d^4(B^0 \to D^*\ell^+\nu_\ell)}{dq^2 d\cos^2\theta_\ell d\cos\theta_{D^*} d\chi} \propto |V_{cb}|^2 \sum_i \mathcal{H}_i(q^2) f_i(\theta_\ell, \theta_{D^*}, \chi)$$

H_i sensitive to New Physic and Form Factors
Many observables can be derived by H_i

$B_s \to D_s^* \mu\nu$

$D_s^* \to D_s \gamma$



Recent literature (non-exhaustive list):

D.Hill et al. JHEP 11 (2019) 133
V. Dedu, A.Poluektov JHEP 07 (2023) 063
B. Bhattacharya et al. JHEP 05 (2019) 191
C.Bobeth et al. EPJ.C 81 (2021) 11, 984
M. Fedele et al. ArXiv;2305.15457
Z. Huang et al. PRD 105 (2022) 1, 013010
B. Bhattacharya et al. JHEP 07 (2020) 07, 194
M. Ivanov et al. PRD 95 (2017) 3, 036021
D. Becirevic et al. NPB 946 (2019) 114707
O. Colangelo, F.DeFazio, JHEP 06 (2018) 082

LHCb prospects on semileptonic decays

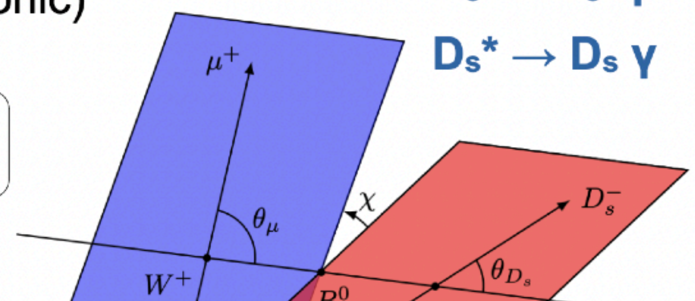
Marcello Rotondo

Beyond R(H_c): going differential

- Angular analyses with semitauonic (and semimuonic) to probe spin structure of physics beyond SM
  - Even in case R(H_c) is SM-like, it will put strong constraints on NP models

$B_s \to D_s^* \mu\nu$

$D_s^* \to D_s \gamma$



$$\frac{d^4(B^0 \to D^*\ell^+\nu_\ell)}{dq^2 d\cos^2\theta_\ell d\cos\theta_{D^*} d\chi} \propto |V_{cb}|^2 \sum_i \mathcal{H}_i(q^2) f_i(\theta_\ell, \theta_{D^*}, \chi)$$

H_i sensitive to New Physic and Form
Many observables can be derived by

Recent literature (non-exhaustive list):

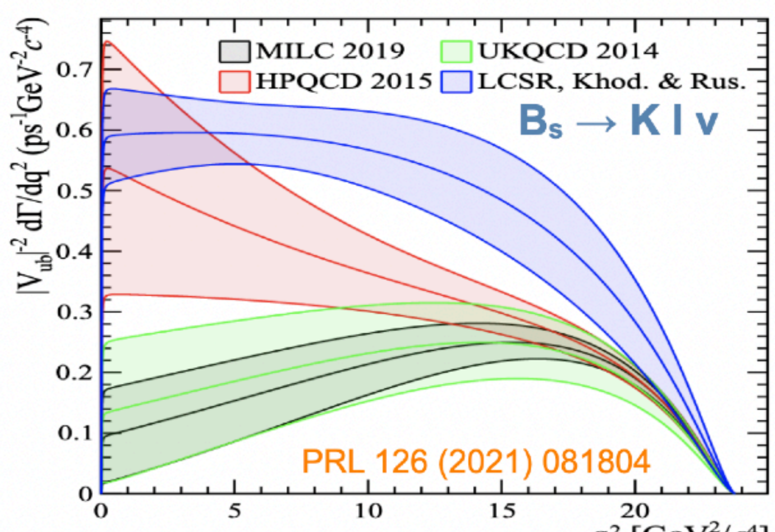
D.Hill et al. JHEP 11 (2019) 133
V. Dedu, A.Poluektov JHEP 07 (2023) 063
B. Bhattacharya et al. JHEP 05 (2019) 191
C.Bobeth et al. EPJ.C 81 (2021) 11, 984
M. Fedele et al. ArXiv;2305.15457

Differential distribution

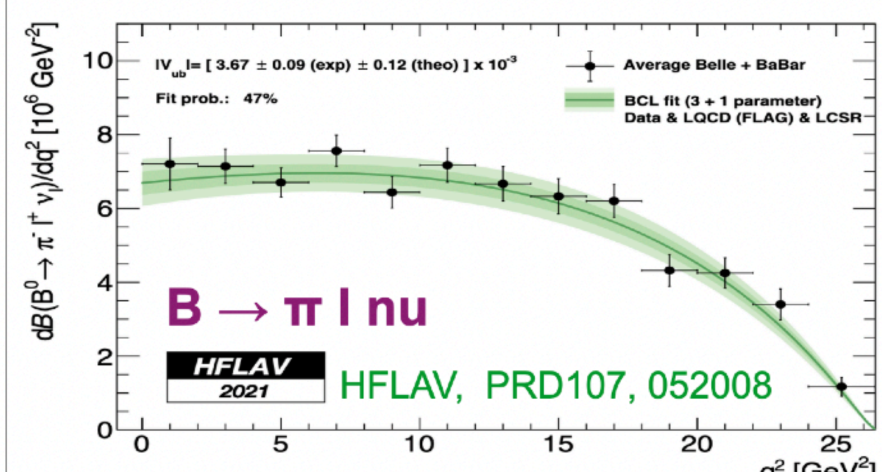
- Measuring partial rate in more q^2 bins
- Constrain the shape of the Form Factor $f_+(q^2)$
  - Large uncertainties due to the extrapolation to the full q^2

With Run2 it should be possible to have 6-8 q^2 bins, studies are ongoing

(differential shape of $\Lambda_b \to p\,\mu\nu$ would allow to validate the FF shape predictions)



It will be possible to perform global fits similar to what is done in HFLAV for $B \to \pi\,\mu\nu$



Global fits
C. Bolognani et al. arXiv:2308.04347
A. Biswas et al. ArXiv:2212.02528
G. Martinelli et al. arXiv:2202.10285

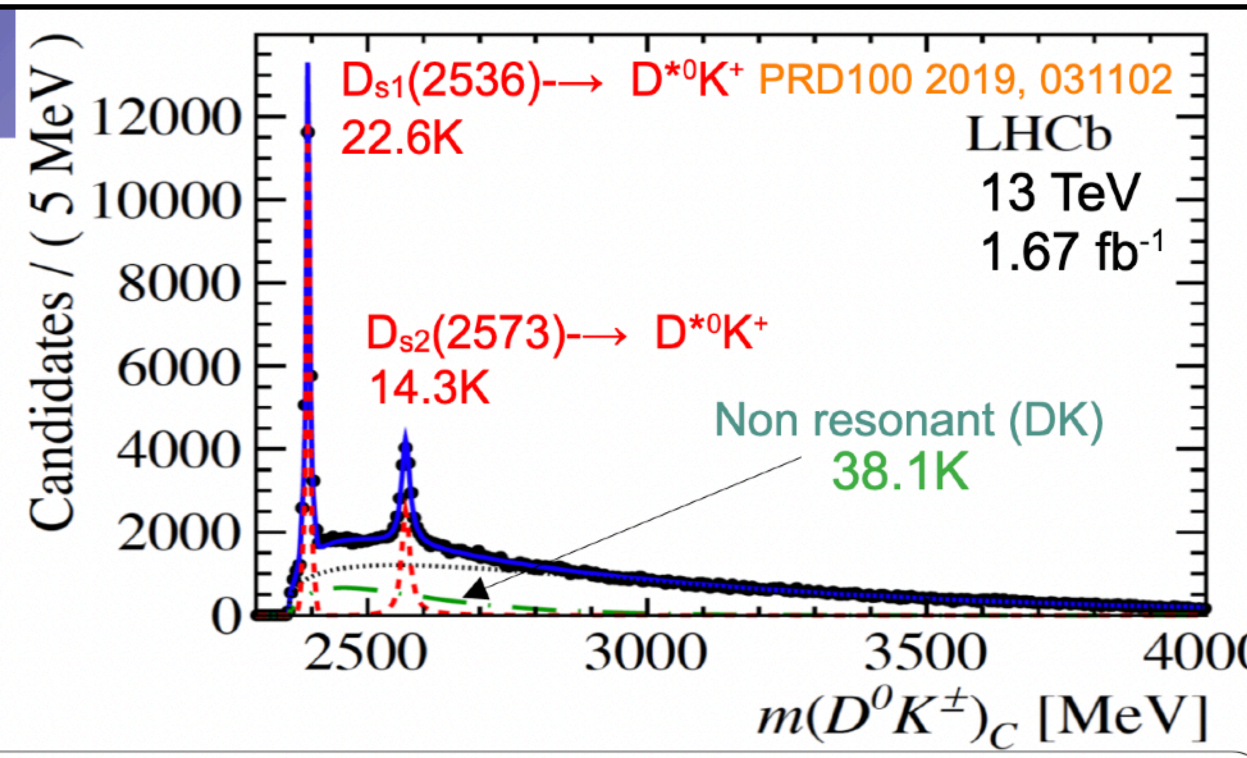
LHCb prospects on semileptonic decays

Marcello Rotondo

Study of $B_s \to D_s^{**}\mu\nu$

- Clean samples of $B_s \to D_{s1}(2536)\mu\nu$ and $B_s \to D_{s2}(2537)\mu\nu$

  - Various ongoing analyses on $B_s \to D_s^{**}\mu\nu$
    - FFs , relative BFs, $R(D_s^{**})$



- Spectrum of excited L=1 D_s^{**} states different with corresponding D^{**} states
- D_s^{**} are all narrow:
  1. New path to understand puzzles in $B \to D^{**}\mu\nu$
  2. SL decays into $D_{s0}(2317)$ and $D_{s1}(2460)$ can shed light on the nature of these states

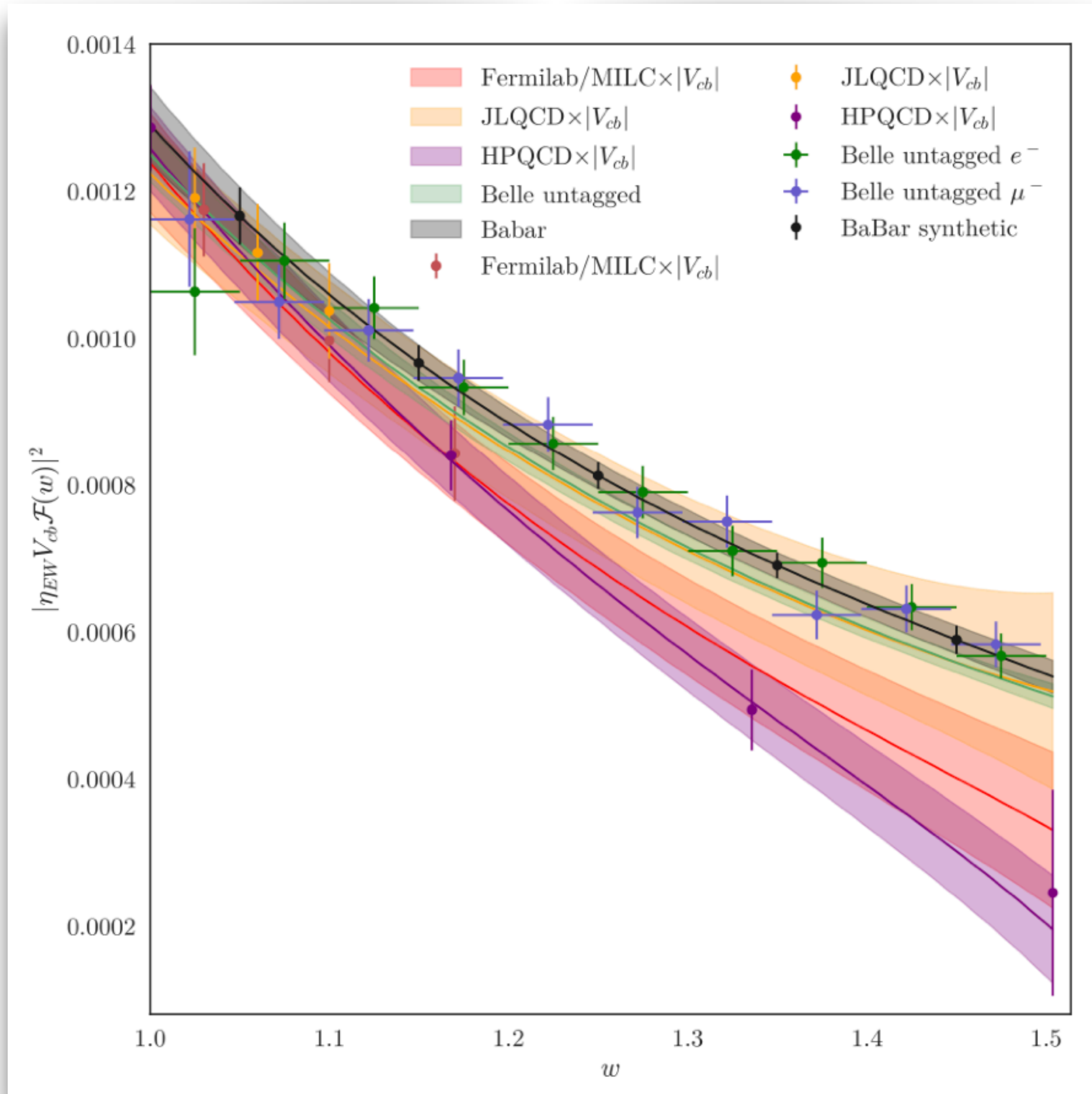
- Precise measurements of exclusive $B_s \to H_{cs}^{**}\mu\nu$ decays allows determination of hadronic moments of X_{cs} in inclusive $B_s \to X_{cs}^{**}\mu\nu$ using a Sum-of-Exclusive Modes
  - Access to OPE parameters for B_s decays: improve predictions of B_s SL and total widths
  - Similar approach done by CDF and DELPHI for B mesons

Inclusive Bs @ Barolo SL WS

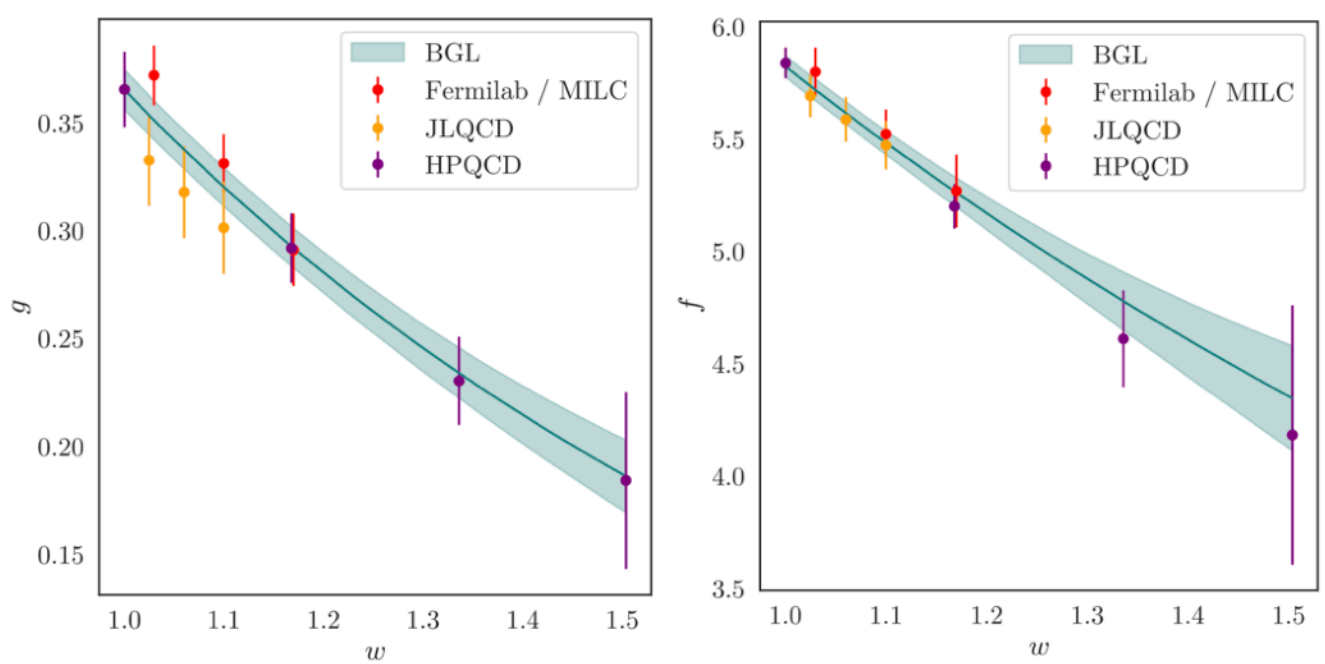
Lattice QCD

Lattice Determinations of $B_{(s)} \to D^{\star}_{(s)}\ell\nu$

Alejandro Vaquero



Semileptonic $B_{(s)}$ decays on the lattice: Combined fits



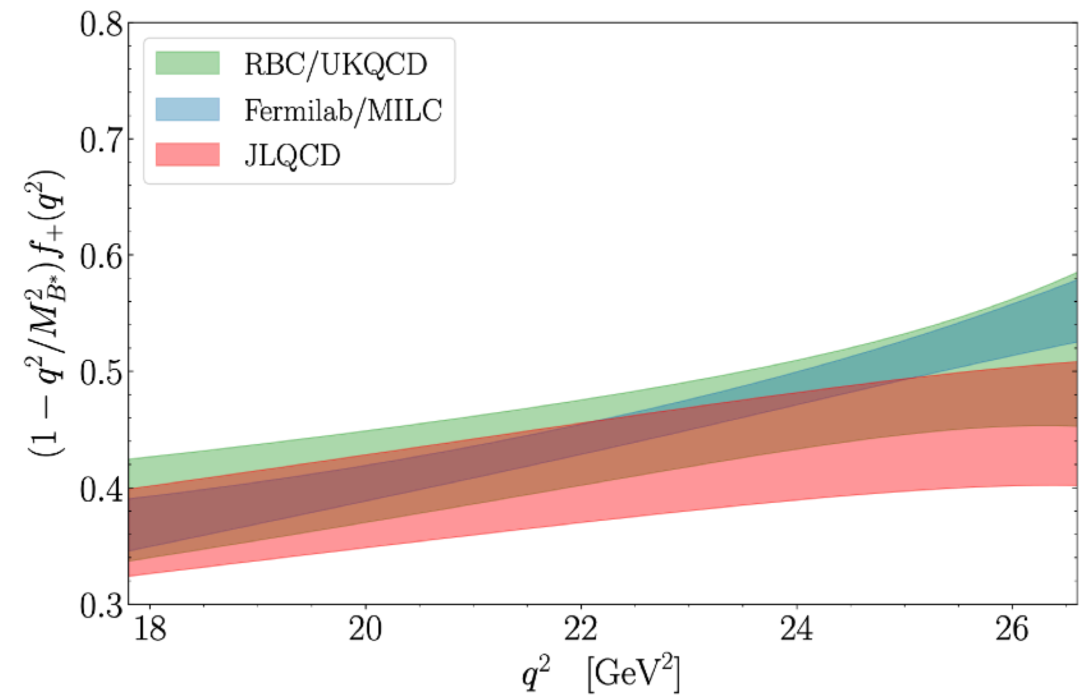
Use the data

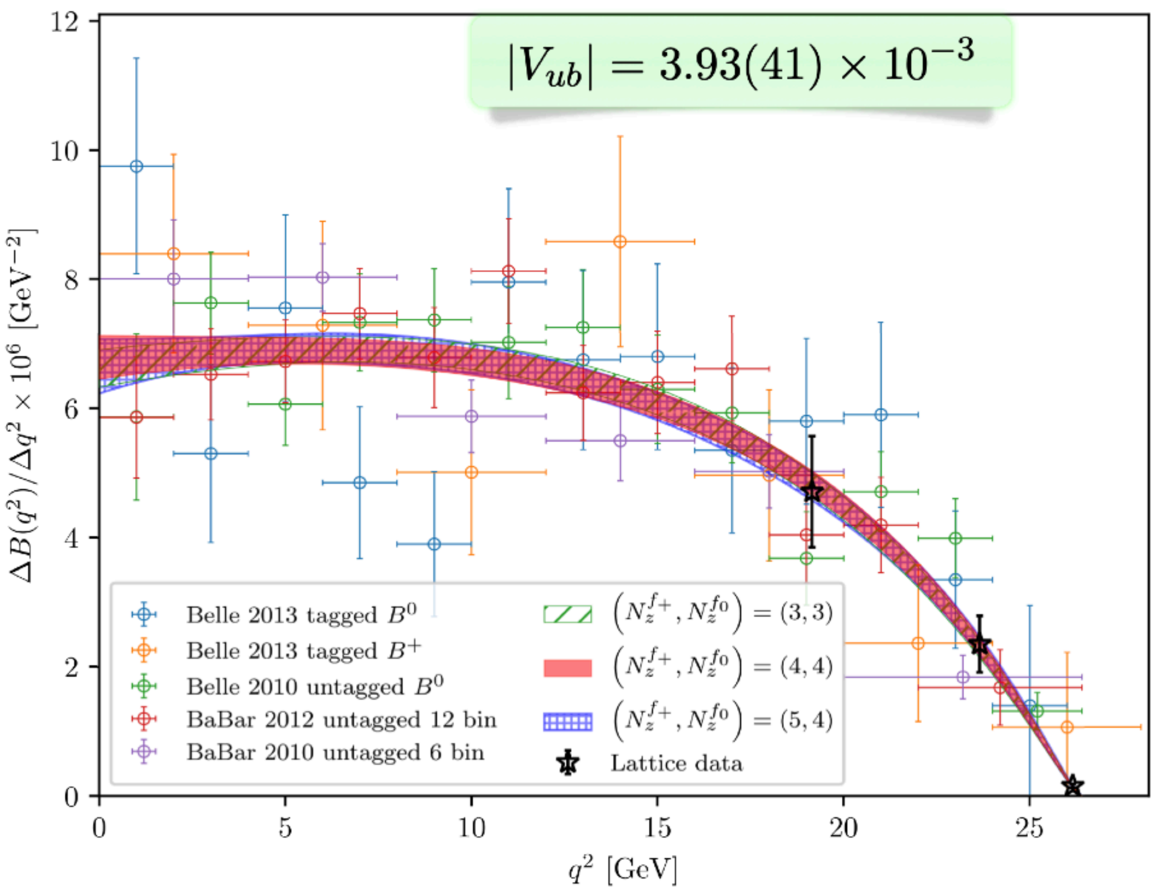
- Current results are not conclusive:
  - $|V_{cb}|$ agrees with previous determinations and the inclusive-exclusive tension remains unsolved
  - Results in $R(D^*)$ are not precise enough
- The LQCD community is determined to improve these results and find better agreements among different collaborations' results
  - The Fermilab / MILC collaboration is preparing **two** new calculations of the $B_{(s)} \to D^*_{(s)}\ell\nu$ form factors
    - Emphasis in heavy quark discretization errors
    - Possibility of correlating these analyses with $B \to D_{(s)}\ell\nu$ analyses, for a correlated $R(D)$ vs $R(D^*)$ plot
    - Possibility of correlating these analyses with $B \to \pi/K$ for a V_{ub} vs V_{cb} correlated plot
- Expect interesting results from these channels in the following years

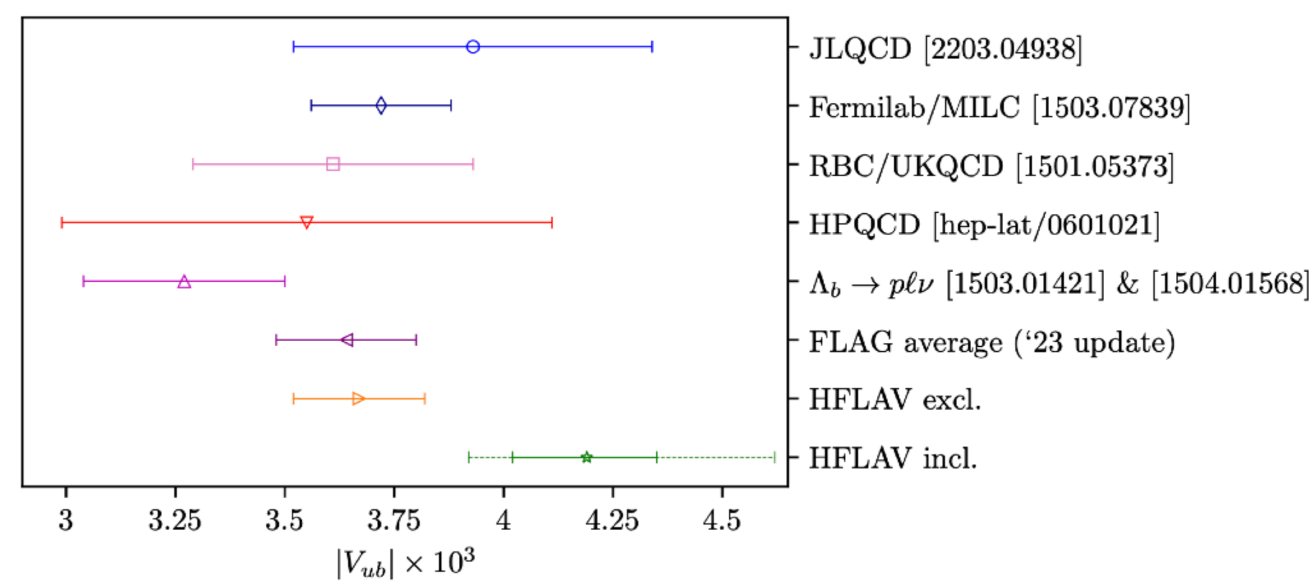
$B \to \pi$ and $B \to D^\star$ from JLQCD   Brian Colquhoun

- ★ We use the Möbius Domain Wall Fermion (MDWF) Action
  - ▶ Pros: fully relativistic & good chiral symmetry
  - ▶ Con: 5th dimension makes MDWF expensive
- ★ MDWF used for all valence & sea quarks
  - ▶ Includes effect of 2+1 quarks in the sea
- ★ Lattice spacings: 0.08, 0.055, 0.44 fm
- ★ Pion masses from 500 MeV down to 230 MeV
- ★ m_b from m_c to $\approx 3m_c$ ($2.44m_c$ for $B \to \pi$)
- ★ $B \to \pi\ell\nu$ first & only fully relativistic calculation
  - ▶ Other collaborations will have fully relativistic results in near future!

$B \to \pi\ell\nu$ Form Factors







JLQCD now working on $B \to \pi\ell\nu$ update: increased statistics, additional m_b values to improve control of extrapolation...

Rare $B \to \pi/K$ decays from lattice QCD

Chris Bouchard

$f_{0,+}$: HPQCD 2006
FNAL/MILC 2015a
RBC/UKQCD 2015
} updates underway

JLQCD 2022 (see Brian Colquhoun's talk)

f_T : FNAL/MILC 2015b

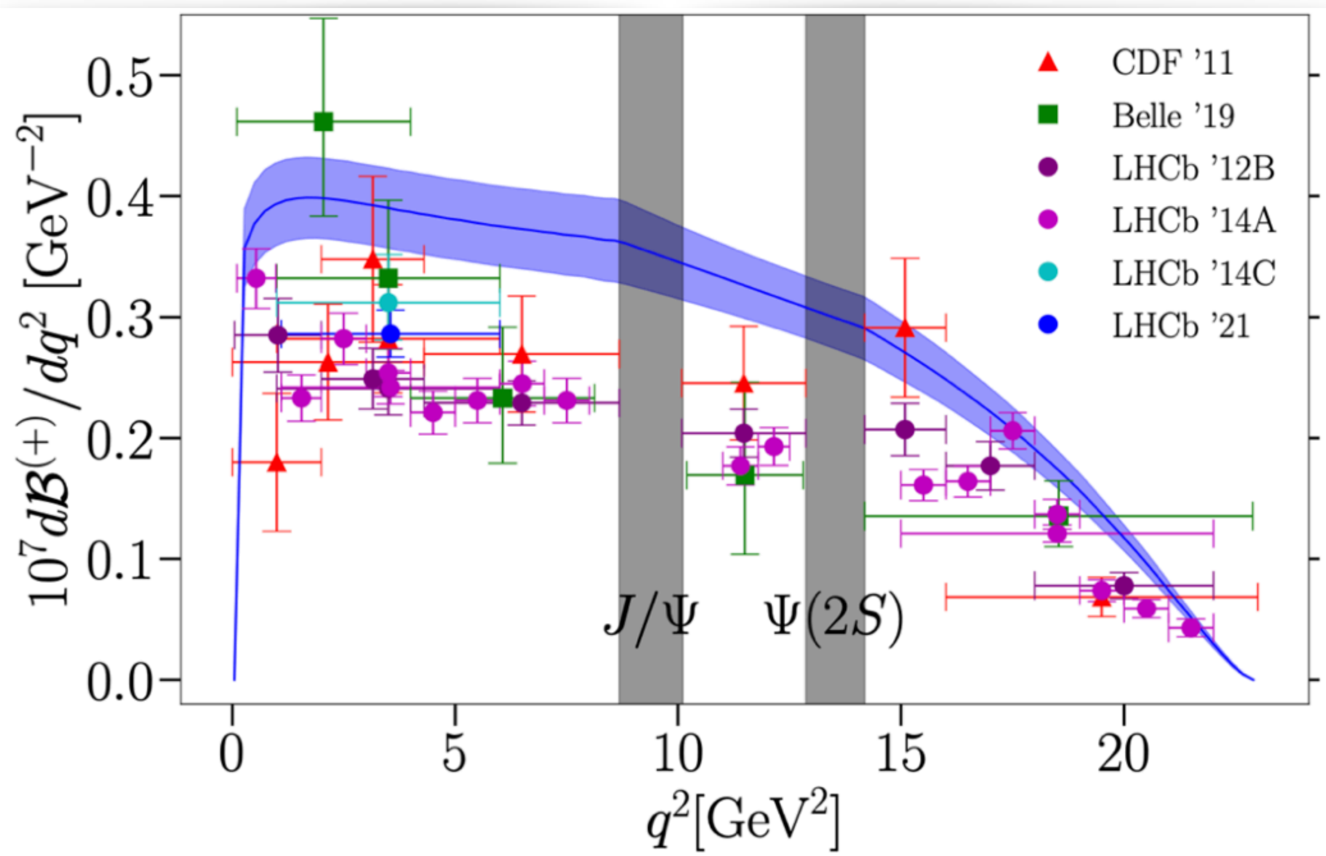
- FNAL/MILC update underway
- calculation by other groups underway

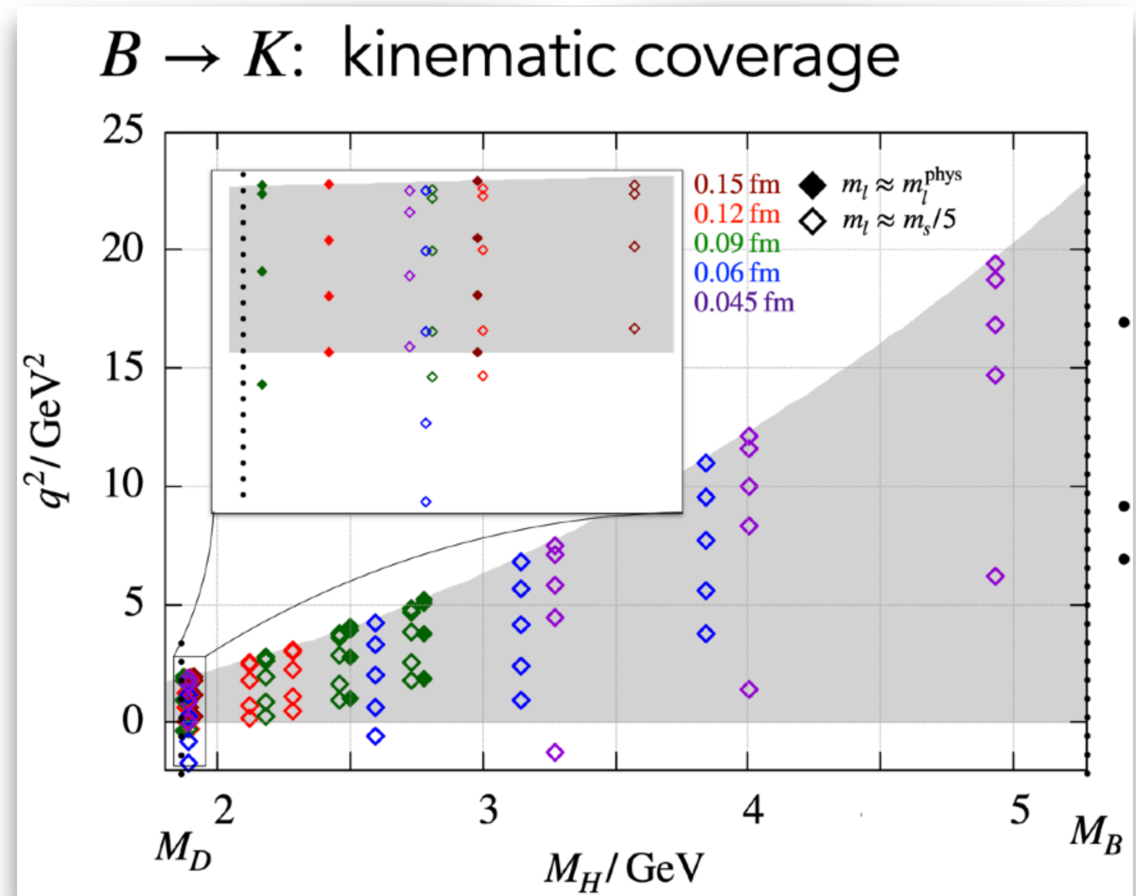
$$\frac{d\Gamma(B \to \pi\ell\ell)}{dq^2} \leftarrow \begin{cases} F_P \\ F_A \\ F_V \end{cases}$$

$$F_P = -m_\ell C_{10}\left[f_+ - \frac{M_B^2 - M_\pi^2}{q^2}(f_0 - f_+)\right]$$

$$F_A = C_{10} f_+$$

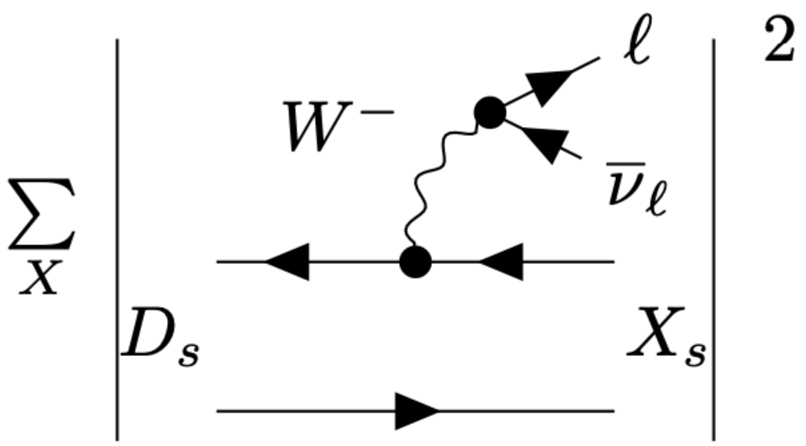
$$F_V = C_9^{\text{eff}} f_+ + \frac{2m_b^{\overline{\text{MS}}}(\mu_b)}{M_B + M_\pi} C_7^{\text{eff}} f_T(\mu_b)$$





Inclusive decays from lattice QCD

Ryan Kellerman

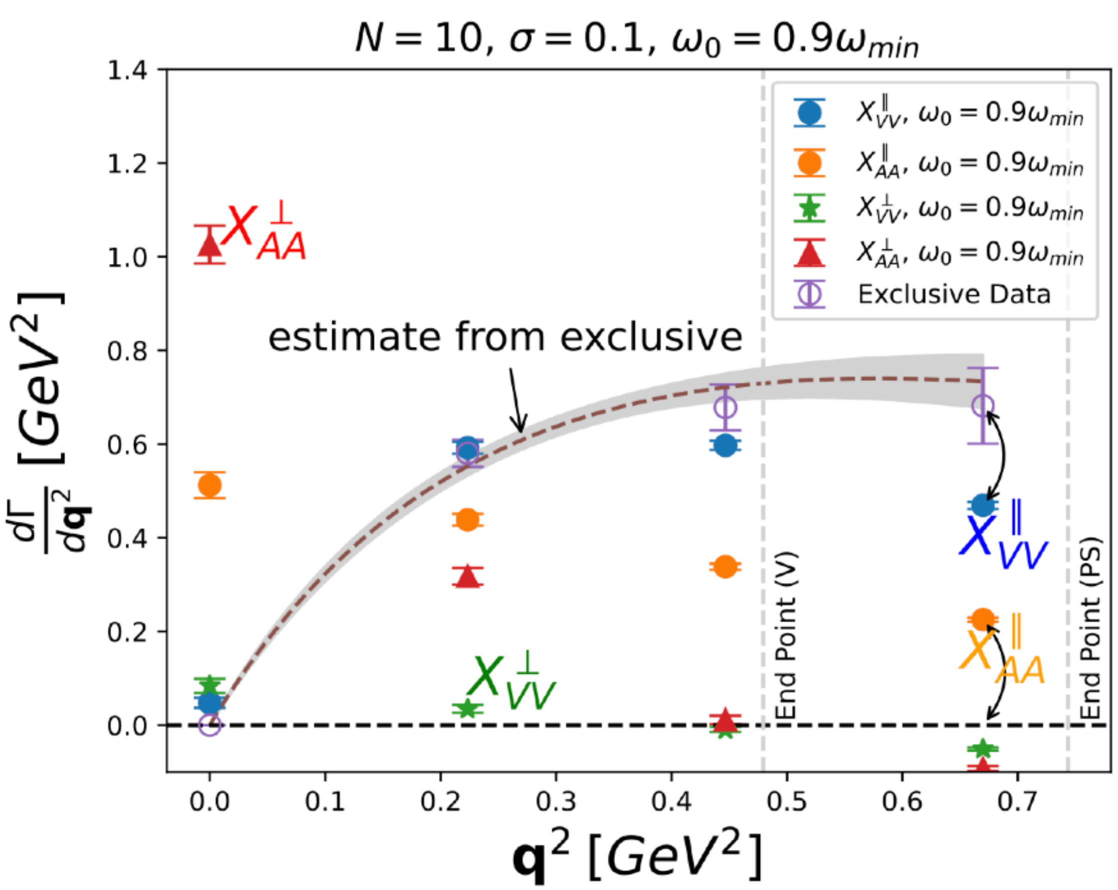


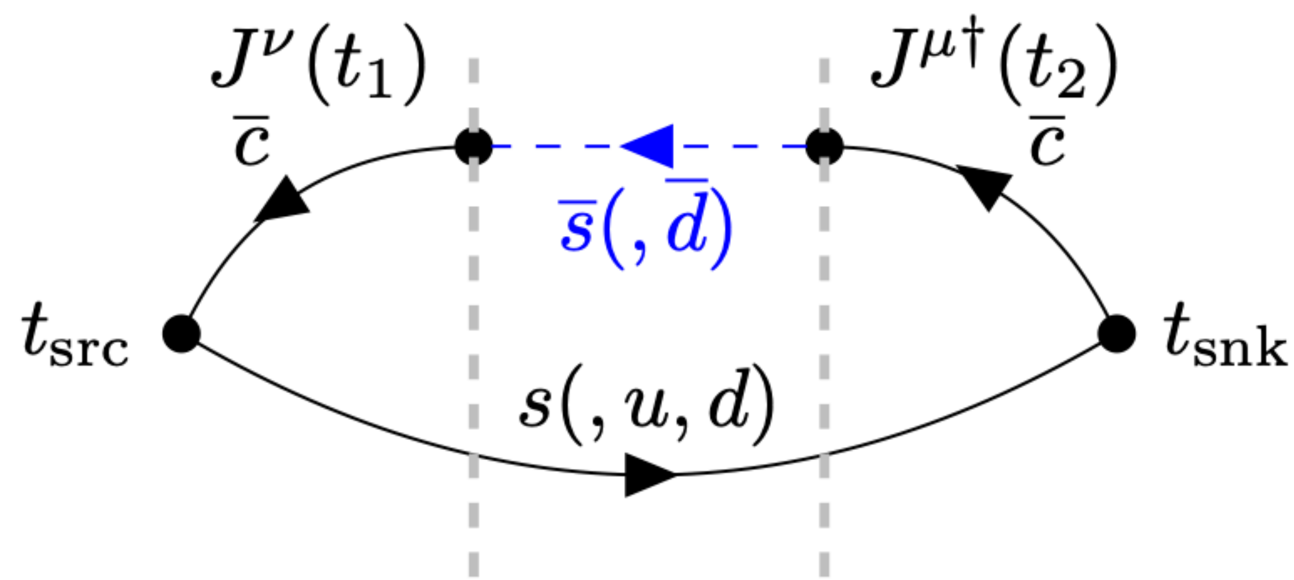
$$\frac{d\Gamma}{dq^2 dq_0^2 dE_l} = \frac{G_F^2 |V_{cs}|^2}{8\pi^2} L_{\mu\nu} W^{\mu\nu}$$

$L_{\mu\nu}$: Leptonic tensor (analytically known)

$W^{\mu\nu}$: Hadronic tensor (nonperturbative QCD)

First numerical results

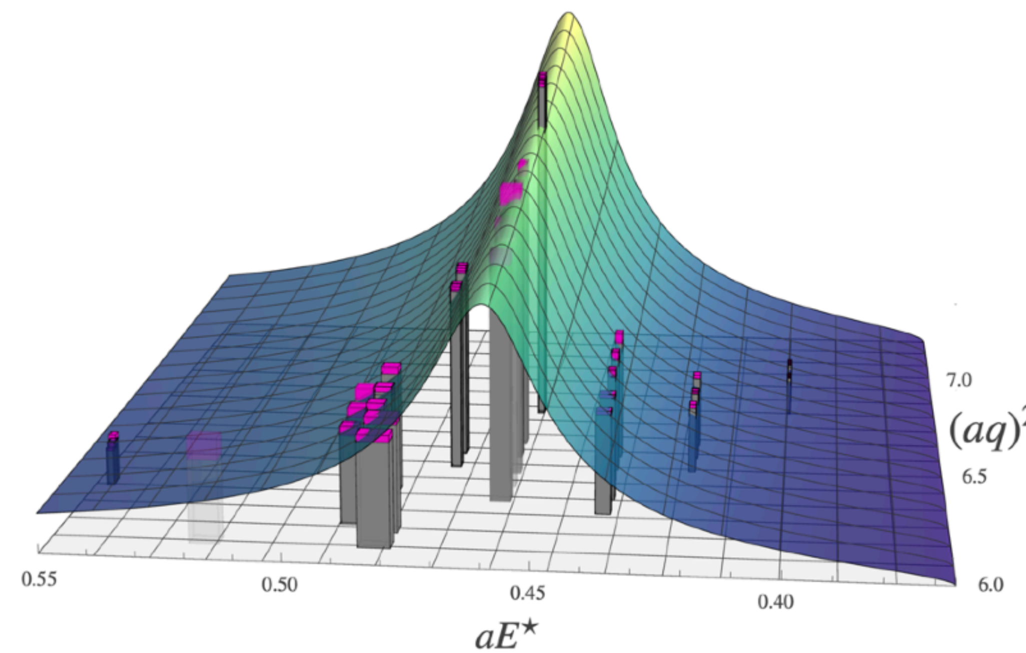




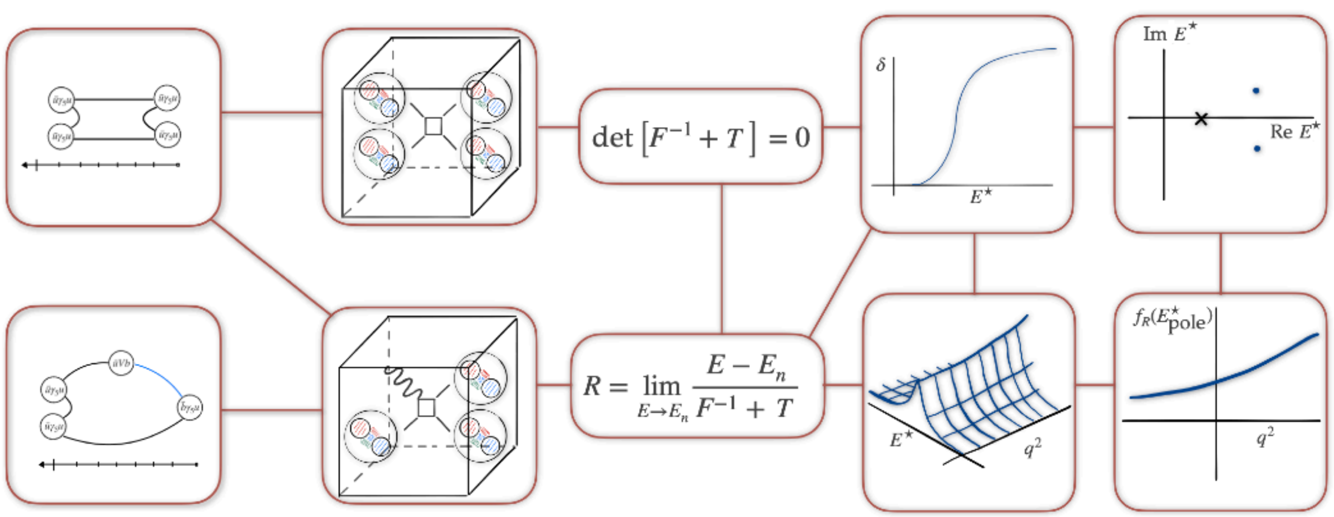
Lattice outlook on $B \to \rho$ and $B \to K^\star$

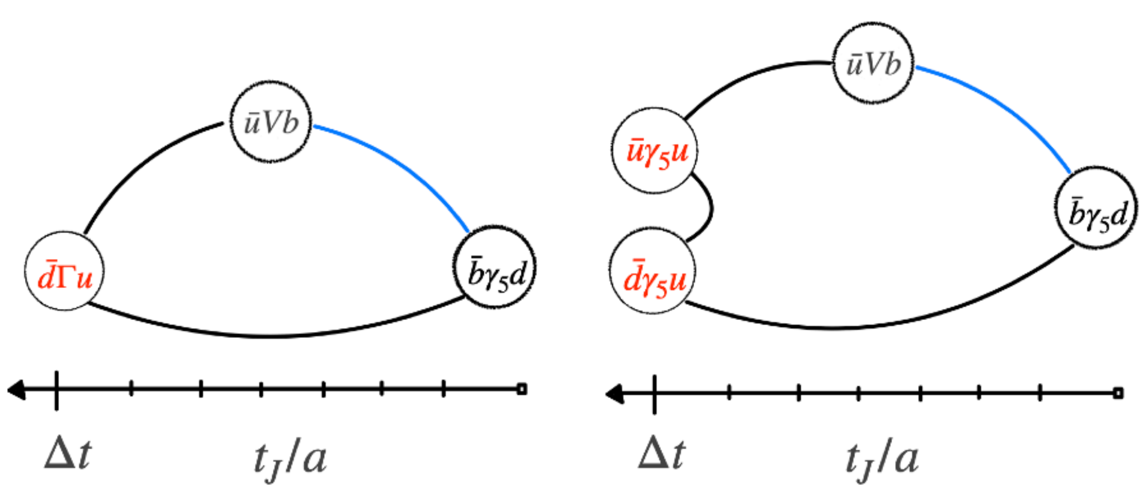
Luka Leskovec

- Qualitatively different methods are needed to handle resonances and/or multihadron final states
- Key challenge: understanding final-state interactions in a finite volume, mapping them to the infinite-volume quantities measured experimentally

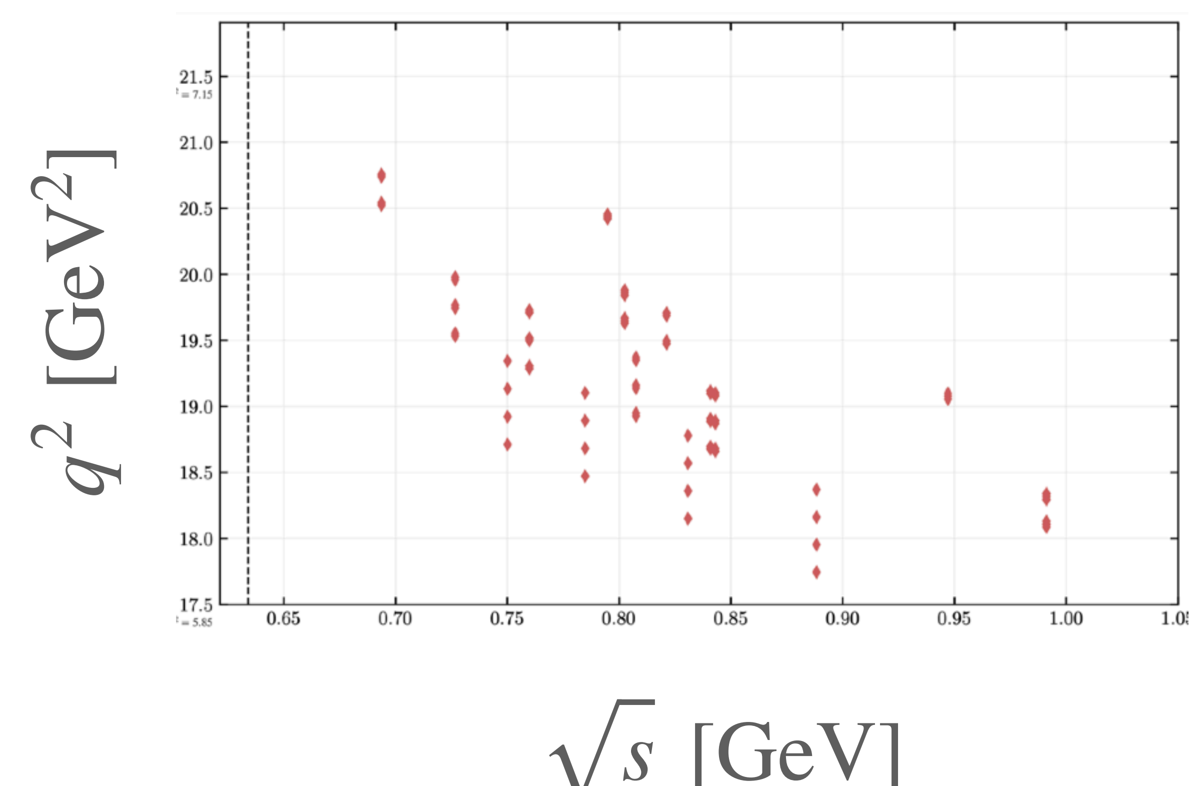


a "how-to" with $B \to \pi\pi(\rho)\ell\bar{\nu}$





Kinematic Coverage



Heavy Quark Effective Theory

HQE in Inclusive SL decays (B2Xc)

K. Keri Vos

$\langle E_\ell^n \rangle, \langle (M_X^2)^n \rangle \quad \langle (q^2)^n \rangle_{\rm cut}$

$\downarrow$

$m_b, m_c, \mu_\pi^2, \mu_G^2, \rho_d^3, r_E, r_G, s_E, s_B, s_{qB}, + \cdots$

$\downarrow$

$$\mathrm{Br}(\bar{B} \to X_c \ell \bar{\nu}) \propto \frac{|V_{cb}|^2}{\tau_B} \left[\Gamma_{\mu_3} \mu_3 + \Gamma_{\mu_G} \frac{\mu_G^2}{m_b^2} + \Gamma_{\tilde{\rho}_D} \frac{\tilde{\rho}_D^3}{m_b^3} + \Gamma_{r_E} \frac{r_E^4}{m_b^4} + \Gamma_{r_G} \frac{r_G^4}{m_b^4} + \Gamma_{s_B} \frac{s_B^4}{m_b^4} + \Gamma_{s_E} \frac{s_E^4}{m_b^4} + \Gamma_{s_{qB}} \frac{s_{qB}^4}{m_b^4} \right]$$

$\downarrow$

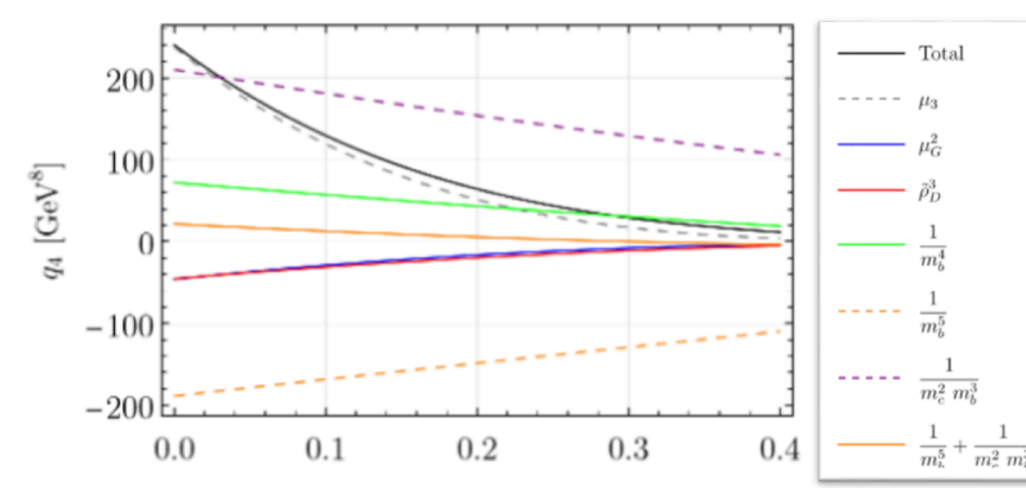
V_{cb}

Challenges:

- Include higher-order $1/m_b$ and α_s corrections
- Proliferation of non-perturbative matrix elements
  - 4 up to $1/m_b^3$
  - 13 up to $1/m_b^4$ Dassinger, Mannel, Turczyk, JHEP 0703 (2007) 087
  - 31 up to $1/m_b^5$ Mannel, Turczyk, Uraltsev, JHEP 1011 (2010) 109

- Simultaneous fit of all measurements
  - α_s^2 corrections required Fael et al. [in progress], corrections are negative Steinhauser, Fael, Schoenwald [2205.03410]

- HQE set up with $m_c/m_b \sim \mathcal{O}(1)$
- IR sensitive terms for $m_c \to 0$ Bigi, Mannel, Turczyk, Uraltsev [0911.3322]
  - at dim-6: $1/m_b^3 \ln m_c^2$
  - at dim-8: $1/m_b^5 m_b^2/m_c^2 \sim 1/m_b^3 1/m_c^2$
- Numerically: $m_c^2 \sim m_b \Lambda_{\rm QCD}$
- New! Calculation and estimate of these effects



E_ℓ, M_X moments:

$$|V_{cb}|_{\rm incl}^{\rm BCG} = (42.00 \pm 0.51) \times 10^{-3}$$

q^2 moments*:

$$|V_{cb}|_{\rm incl}^{q^2} = (41.69 \pm 0.63) \times 10^{-3}$$

HQE in Inclusive SL decays (B2Xu)

K. Keri Vos

Inclusive $B \to X_u \ell \nu$

- Experimental cuts necessary to remove charm background
- Local OPE as in $b \to c$ cannot work
- Switch to different set-up using light-cone OPE
- Introduce non-perturbative shape functions ($\sim$ parton DAs in DIS)
- Different frameworks: BLNP, GGOU, DGE, ADFR

Update BLNP! In progress!!

- In progress: include known α_s^2 corrections
- Moments of shape functions can be linked to HQE parameters in $b \to c$
  - In progress: include higher-moments
  - kinetic mass scheme as in $b \to c$
- Shape function is non-perturbative and cannot be computed
  - In progress: new flexible parametrization

Updated predictions for $R(D^{(\star)})$ using the residual chiral expansion

Markus Prim

RCE conjecture: matrix elements involving (many) $\not{p}_\perp$ OP insertions are typically small

Truncate at $\mathcal{O}(\theta^2)$

$\Rightarrow$ Captures all NLO + NNLO with zero OP insertions

Key Idea: Counting $\not{p}_\perp$ insertions provides and additional classification of terms vs $1/m_Q$ power expansion.
Deform QCD by including a $\not{p}_\perp$ power-counting parameter θ

BLPRXP Form Factors for $B \to D^{(*)}\ell\bar{\nu}_\ell$

Expansion to order $\mathcal{O}\left(1/m_{b,c}^{(2)}\right)$, $\mathcal{O}(1/(m_b m_c))$

$$\frac{\langle H_c|\bar{c}\Gamma b|H_b\rangle}{\sqrt{m_{H_c} m_{H_b}}} \propto 1 + \underbrace{\frac{1}{2m_c} + \frac{1}{2m_b}}_{+3} + \overbrace{\underbrace{\frac{1}{4m_c^2}}_{+20\,\to\,+1} + \frac{1}{2m_b^2} + \frac{1}{4m_c m_b}}^{+32\,\to\,+3}$$

$+32 \to +3$: $\varphi_1(w), \beta_2(w), \beta_3(w)$

$+3$: $\eta(w), \chi_2(w), \chi_3(w)$

$+20 \to +1$: $\varphi_1(w)$

Number of non-perturbative parameters under control

Supplemental power counting in the transverse residual momentum $\not{p}_\perp$
→ Drastic reduction of the non-perturbative parameters

$\Lambda_b \to \Lambda_c \ell \bar{\nu}_\ell$

- Only 2 subleading IW at $\mathcal{O}\left(\frac{1}{m_c^2}\right)$ for $\Lambda_b \to \Lambda_c \ell \bar{\nu}_\ell$ (no $\mathcal{O}\left(\frac{1}{m_b m_c}\right)$ included)
- Fit without RC yields only 1 significant parameter contributing to subleading IW

- After application of the RC: ($\mathcal{O}\left(\frac{1}{m_b m_c}\right)$ included) only 1 free parameter remaining to describe the subleading IW functions: φ_1

→Ideal process to test if RC yields compatible results

NLO QCD corrections to inclusive $B \to X_c \tau \nu$ decay rate and spectrum up to $1/m_Q^3$

Daniel Moreno Torres

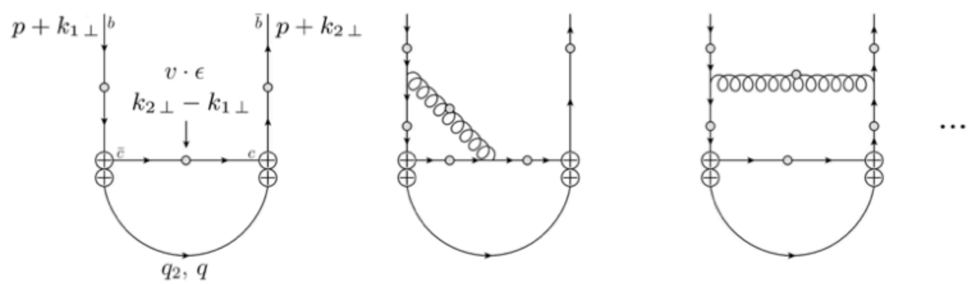
$$\Gamma(B \to X_c \tau \bar{\nu}_\tau) = \frac{G_F^2 m_b^5}{192\pi^3}|V_{cb}|^2\left[C_0\left(1-\frac{\mu_\pi^2}{2m_b^2}\right)+C_{\mu_G}\left(\frac{\mu_G^2}{2m_b^2}-\frac{\rho_{LS}^3}{2m_b^3}\right)-C_{\rho_D}\frac{\rho_D^3}{2m_b^3}\right]$$

Wilson coefficients C_i Hadronic parameters μ_π^2, μ_G^2, ρ_{LS}^2, ρ_D^3

Differential rate in the lepton invariant mass at $\mathcal{O}(\alpha_s/m_b^3)$

At α_s/m_b^3 we only need to determine the coefficient of ρ_D (Darwin term)

- **Take the amplitude** of quark to quark-gluon scattering with kin. conf.



with $p^2 = m_b^2$ and $k_\perp^\mu = k^\mu - v^\mu(v\cdot k)$.

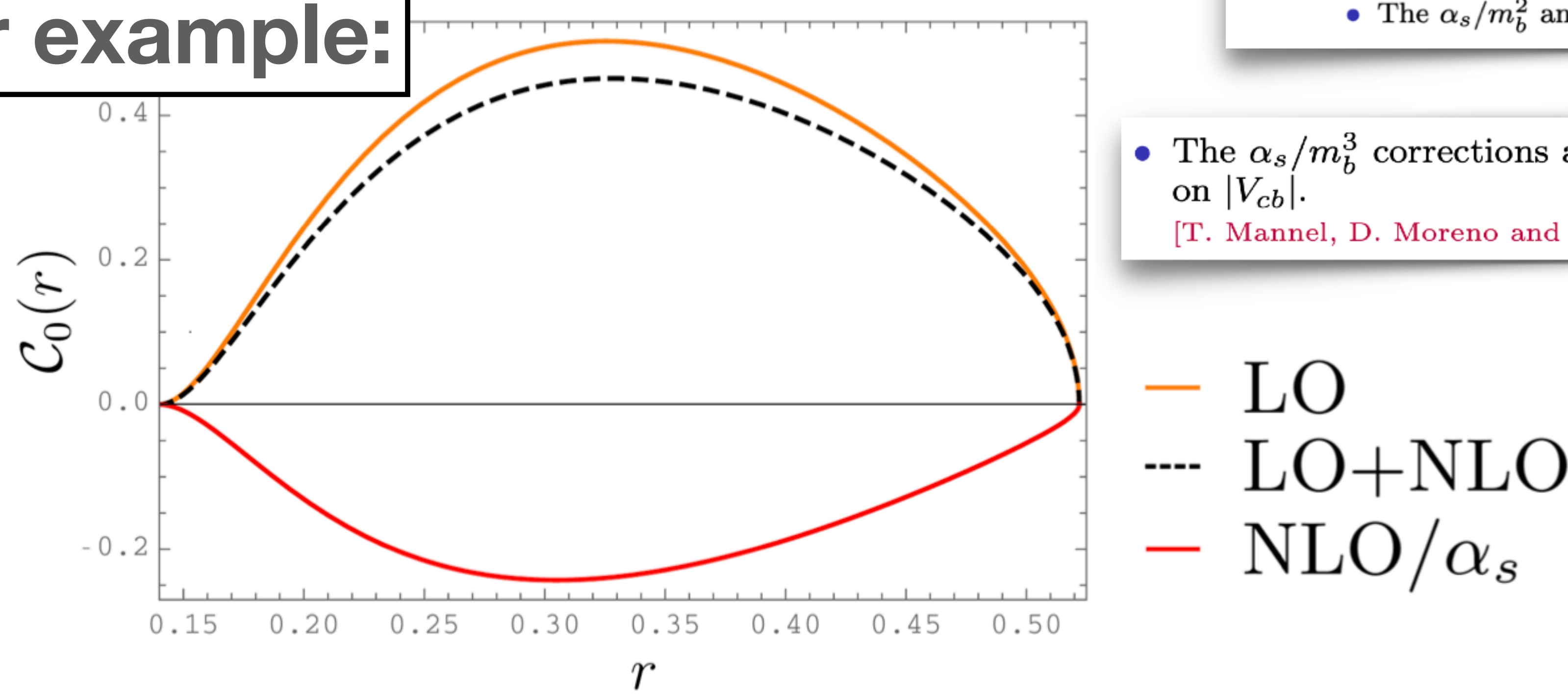
- **Expand** to quadratic order in the small momenta $k_{1\perp}$, $k_{2\perp}$.
- **Project** to the Darwin operator, i. e pick up $k_{1\perp}^{(\alpha}k_{2\perp}^{\beta)}$ structure.

Final remarks

$B \to X_c \tau \bar{\nu}_\tau$

- We have computed the α_s/m_b^2 and α_s/m_b^3 corrections to $\Gamma(B \to X_c\tau\bar{\nu}_\tau)$ and $d\Gamma(B \to X_c\tau\bar{\nu}_\tau)/dr$ with full dependence on m_c and m_τ analytically. [D. Moreno, PRD **106** (2022), 114008]
- Current knowledge of the HQE for $B \to X_c\tau\bar{\nu}_\tau$ decay rate and q^2-distribution: $(\alpha_s^2,\ \alpha_s/m_b^3)$.
- We propose to analyze the Γ, $\hat{M}_n$ and $R_n^{q\ell/q'\ell'}$.
- May provide valuable complementary information to $R(D^{(*)})$ where a more than 3σ deviation from the SM is present. [Z. Ligeti and F. J. Tackmann, PRD **90** (2014), 034021] [M. Rahimi and K. K. Vos, JHEP **11** (2022), 007]
- The LO $1/m_b^3$ corrections ($\sim 10\%$) correction to the leading term.
- The α_s/m_b^2 and α_s/m_b^3 corrections ($\sim 1\%$) correction.

For example:



- The α_s/m_b^3 corrections are ($\sim 1\%$), and we expect a small but visible impact on $|V_{cb}|$. [T. Mannel, D. Moreno and A. A. Pivovarov, PRD **105** (2022), 054033]

New physics contributions to moments of inclusive $b \to c$ decays

Matteo Fael

GOAL: comprehensive model-independent analysis of all possible types of NP effects in $B \to X_c \ell \bar{\nu}_\ell$

HQE with NP effects

Series expansion in three parameters:

Λ_{QCD}/m_b, α_s, and $(v/\Lambda_{NP})^2$

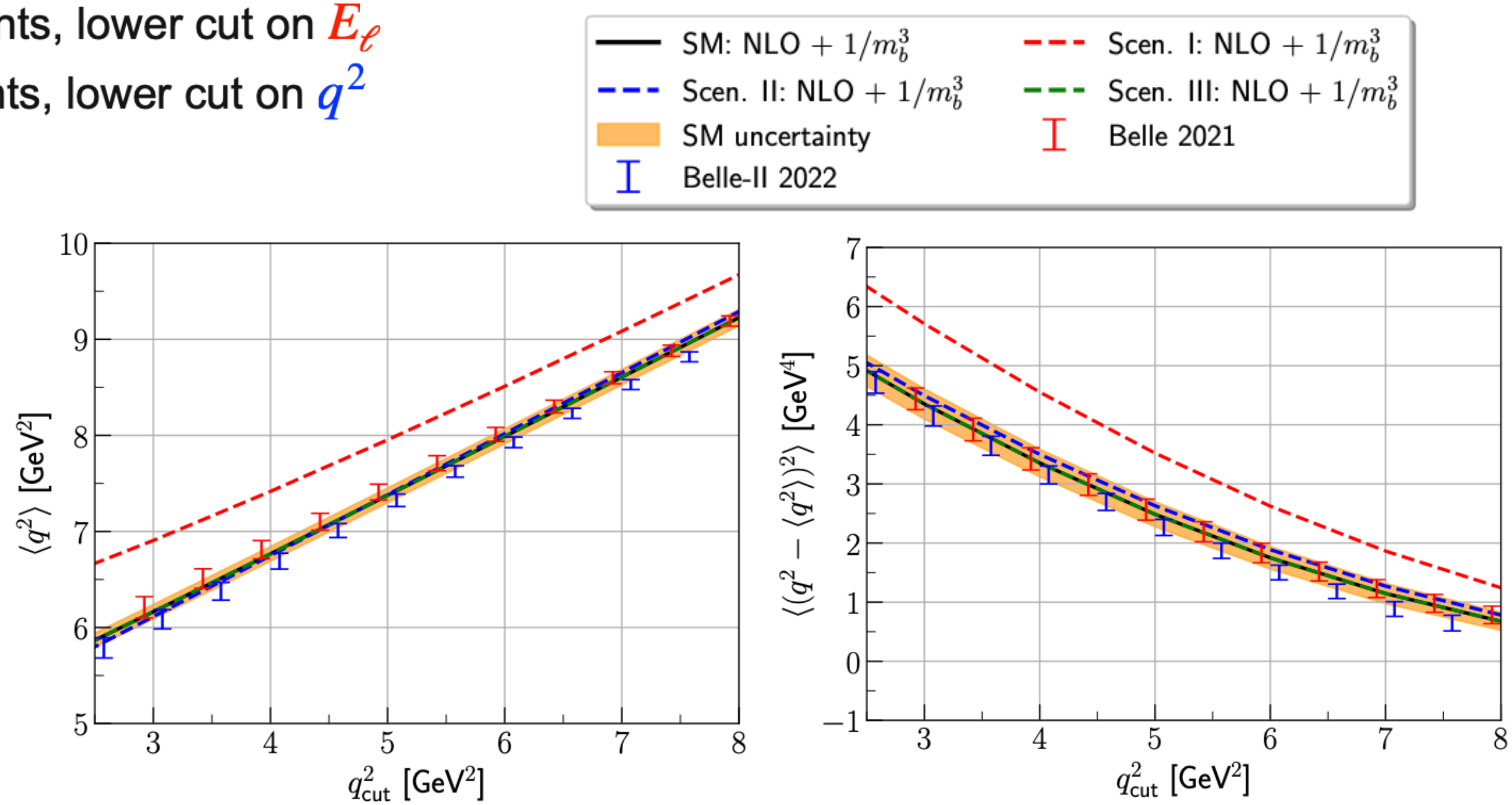
We obtain results for:

- Charged-lepton energy moments, lower cut on E_ℓ
- Hadronic invariant mass moments, lower cut on E_ℓ
- Leptonic invariant mass moments, lower cut on q^2

To properly catch the leading effects:

- $(v/\Lambda_{\rm NP})^2 \times \alpha_s^0 \times (1/m_b)^0$: NP at tree level in the free-quark approximation.
- $(v/\Lambda_{\rm NP})^2 \times \alpha_s^0 \times (1/m_b)^{2,3}$: power-suppressed terms for NP effects
- $(v/\Lambda_{\rm NP})^2 \times \alpha_s^1 \times (1/m_b)^0$: QCD NLO corrections to NP effects

NP Scenarios	C_{V_L}	C_{V_R}	C_{S_R}	C_{S_L}	C_T
I	0	0	1	1	0
II	0	0	0	-1	0.5
III	-1	0.5	0	0	0



Open source code

https://gitlab.com/vcb-inclusive/npinb2xclv

https://gitlab.com/vcb-inclusive/kolya

Combined analyses

Unitarity Constraints and the Dispersive Matrix

Ludovica Vittorio

NOVELTY:

***Importance Sampling (IS) procedure for DM** with high number of inputs, see* **arXiv: 2309.02135**

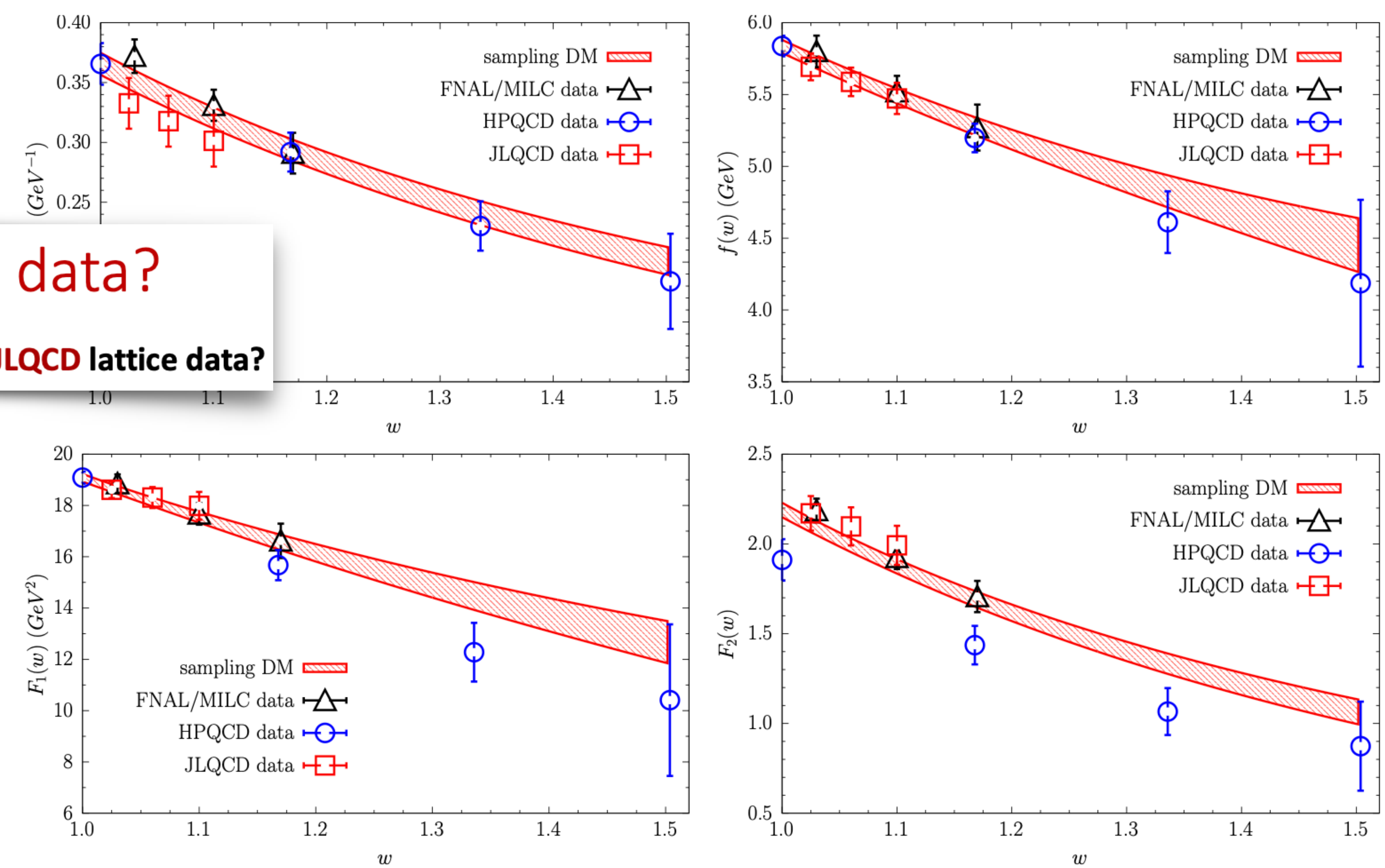
The Dispersive Matrix (DM) method

Our goal is to describe the FFs using a novel, non-perturbative and model independent approach: starting from the available LQCD computations of the FFs in the high-q^2 (or low-w) regime, we extract the FFs behaviour in the low-q^2 (or high-w) region!

- Pioneering works from S. Okubo [PRD, 3 (1971); PRD, 4 (1971)], C. Bourrely et al [NPB, 189 (1981)] and L. Lellouch [NPB, 479 (1996)]
- New developments in PRD '21 (2105.02497)

The resulting description of the FFs

- is entirely based on first principles (LQCD evaluation of 2- and 3-point Euclidean correlators)
- is independent of any assumption on the functional dependence of the FFs on the momentum transfer
- can be applied to theoretical calculations of the FFs, but also to experimental data
- keep theoretical calculations and experimental data separated
- is universal: it can be applied to any exclusive semileptonic decays of mesons and baryons



Combined study of all the lattice data?

What about a **combined study of FNAL/MILC + HPQCD + JLQCD lattice data?**

Model-independent description of $B \to D\pi\ell\nu$ decays

Florian Herren

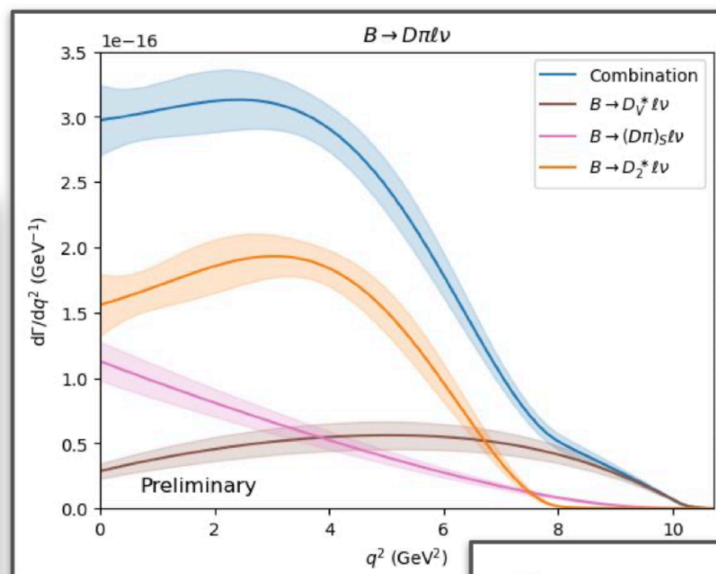
Form Factor decomposition

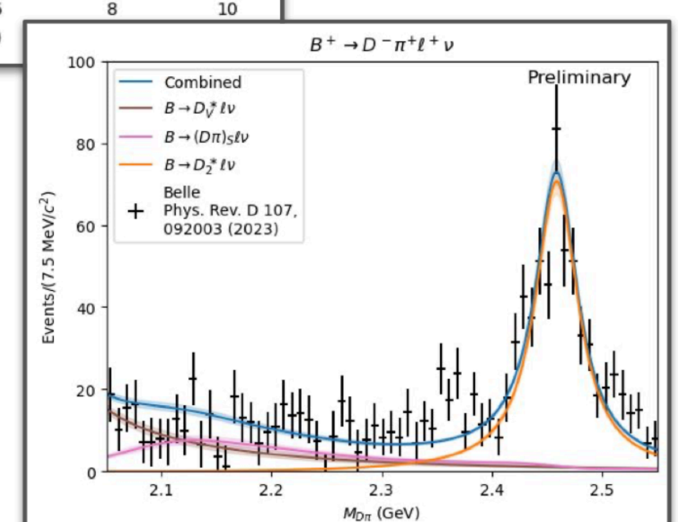
- We perform a partial wave decomposition in the D-π system
- 2 FFs for l = 0, 4 for every higher partial wave
- Setting the D-π invariant mass to a resonances mass, picking a specific partial wave and replacing L by the polarization tensors yields the standard expressions for the D* and D_2^*
- In general, the FFs are complex

- Unitarity bounds follow from a dispersion relation via a BGL-like analysis
- Physics inputs:
  - LQCD $D\pi$ (HadSpec Collaboration)
  - Measured (w/mass) spectra from experiment (Belle)
  - Reasonable (and systematically improvable) assumptions about higher partial waves.

Conclusion

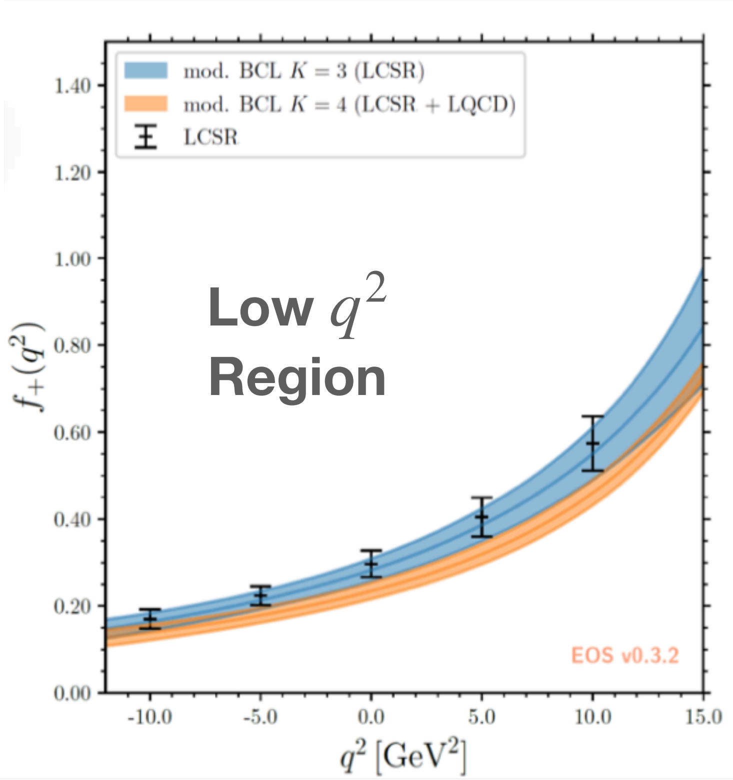
- We developed a model-independent description of $B \to D\pi\ell\nu$
- By combining meson-meson scattering phase-shifts with $B \to D\ell\nu$ in the soft-Goldstone limit we obtained predictions for the S-Wave $B \to D\pi\ell\nu$, $B \to D\eta\ell\nu$ & $B \to D_s K\ell\nu$ decays
- We re-analyzed $B \to D_2^*\ell\nu$ decays and found discrepancies with the literature
- The framework developed is extendable to other final states, as well as Cabibbo-suppressed decays

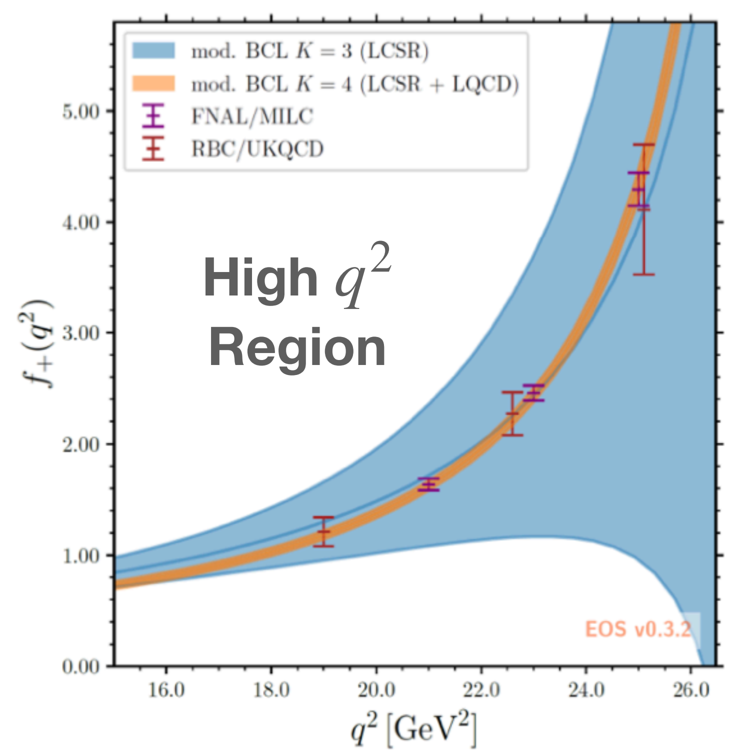




$|V_{ub}|$ and the potential impact of new physics in exclusive $b \to u\ell\nu$ decays

Blazenka Melic





- we revisit **LCSR prediction for the full set of B → π form factors** by simultaneously fitting them, including correlations and focus on systematic uncertainties by using Bayesian fit and extrapolation in the full q^2 region
- we carry out combined fit with precise QCD lattice results and provide **the most up-to-date theoretical (LCSR + LQCD) form factors in B → π decays**
- we **add B → ρ, ω** decays and usings average of experimental measurements of **B → (π , ρ, ω) l ν** with correlations we perform fits and **extract |Vub|$_{excl}$**

$$|V_{ub}|^{B\to\pi,\rho,\omega} = (3.59^{+0.13}_{-0.12}) \times 10^{-3}$$

compatible with the global CKMfitter fit:

$$|V_{ub}|^{\mathrm{CKMfitter}} = (3.67^{+0.09}_{-0.07}) \times 10^{-3}$$

- with perform **WET (with only left-handed neutrinos) fit** of all B → (π , ρ, ω) l ν data, and conclude that the **BSM is preferred over SM interpretation**
  /more input is needed, in particular from theory side on **B → (ρ, ω) l ν** decays/
- we provide Gaussian Mixture Model of marginalized WET Wilson coefficients
  - to provide computationally efficient way of using the WET parameter space without having to re-run a complicated, computationally expensive statistical analysis
  /in ancillary material of 2302. 05268 paper/

$$B^0 \to \pi^+ \ell^- \bar{\nu}$$

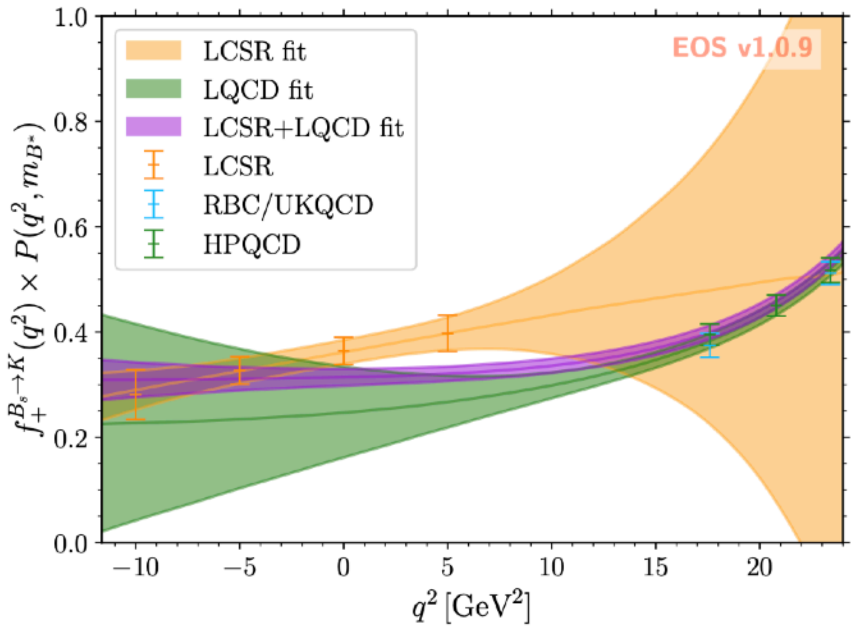
exp: HFLAV average (Babar & Belle)
th: FF from LCSR + lattice, BCL q^2 param of FF

$$B^- \to \rho \ell^- \bar{\nu}$$
$$B^- \to \omega \ell^- \bar{\nu}$$

exp: average from Bernlochner, Prim, Robinson, 2104.05739 (Babar & Belle)
th: FF from LCSR [Bharucha, Strub, Zwicky (BSZ) 2015], BSZ q^2 param. of FF

Combining lattice and sum rules to determine $|V_{ub}|/|V_{cb}|$

Carolina Da Silva Bolognani

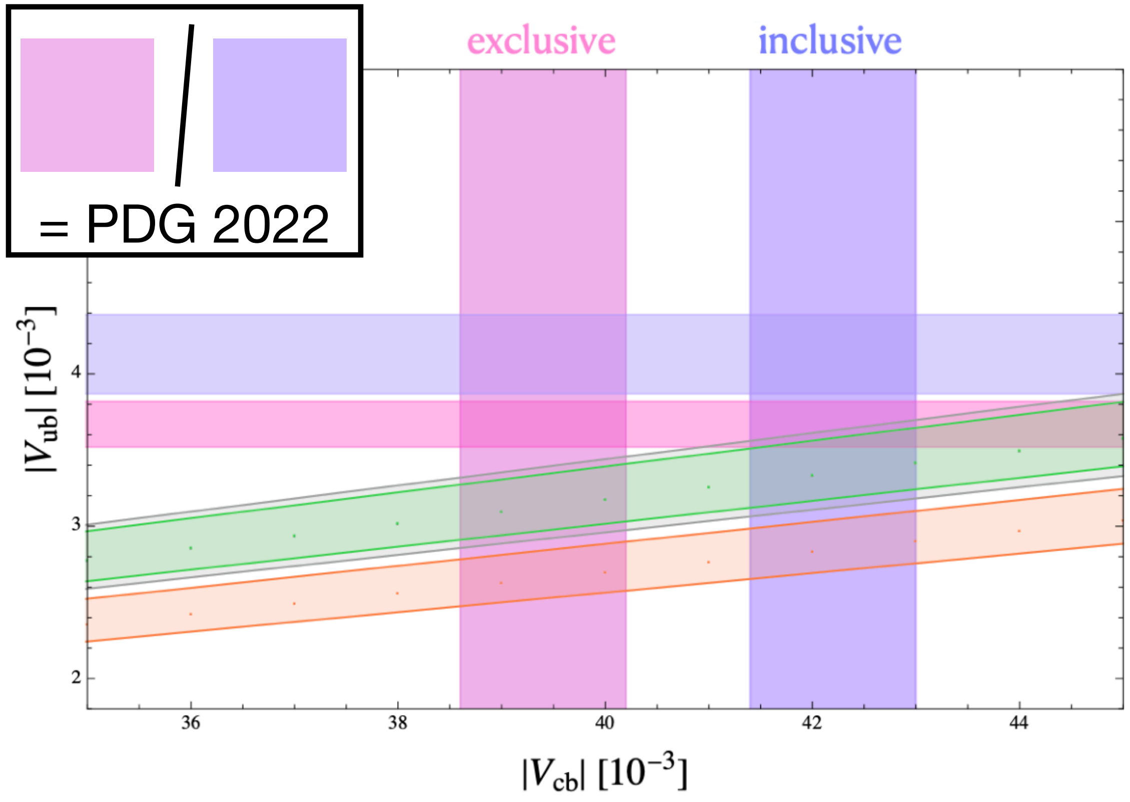


New determination of $|V_{ub}/V_{cb}|$

- Infer full set of $\bar{B}_s \to K$ form factors over the full q^2 range
- Steps:
  - ★ Update LCSR form factor results with study of duality threshold parameters
  - ★ Add LQCD results to constrain the parametrisation at high q^2
  - ★ Fit to both theory inputs using a unitarity-bounded parametrisation
  - ★ Extract $|V_{ub}/V_{cb}|$ from the $B_s^0 \to K^- \mu^+ \nu_\mu$ LHCb measurement
- Analysis done with EOS flavour physics software

$$q^2 > 7\ \text{GeV}^2 \Rightarrow \left|\frac{V_{ub}}{V_{cb}}\right| = 0.0801 \pm 0.0047$$

$$q^2 < 7\ \text{GeV}^2 \Rightarrow \left|\frac{V_{ub}}{V_{cb}}\right| = 0.0681 \pm 0.0040$$



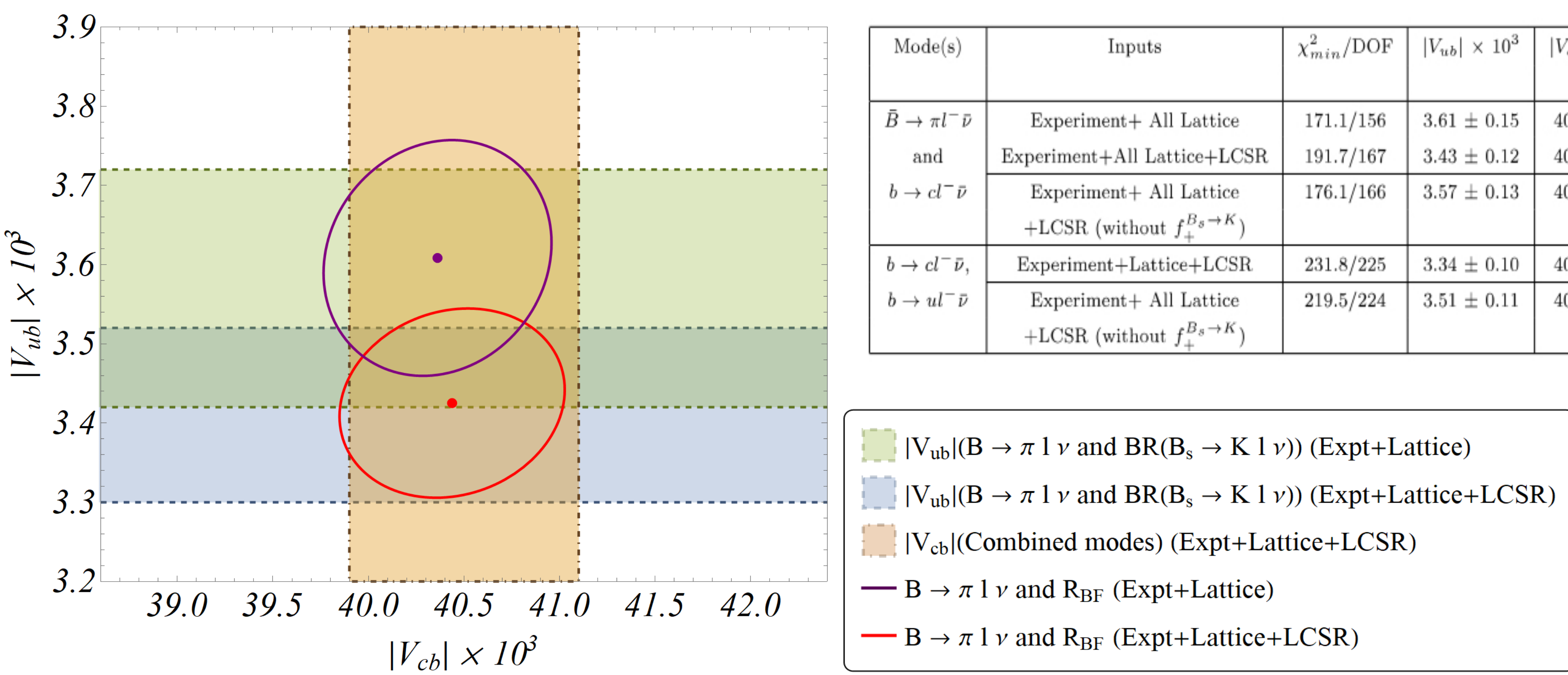
Extraction of the ratio $|V_{ub}|/|V_{cb}|$ from a combined study of the exclusive decays

Ipsita Ray

$$|V_{ub}|^{excl} \leftarrow \begin{cases} B \to \{\pi/\rho/\omega\}\ell\nu \\ B \to K\mu\nu \end{cases} \qquad |V_{cb}|^{excl} \leftarrow \begin{cases} B \to D^{(\star)}\ell\nu \\ B_s \to D_s^{(\star)}\ell\nu \end{cases}$$

Correlations in the $|V_{ub}|$ and $|V_{cb}|$ plane

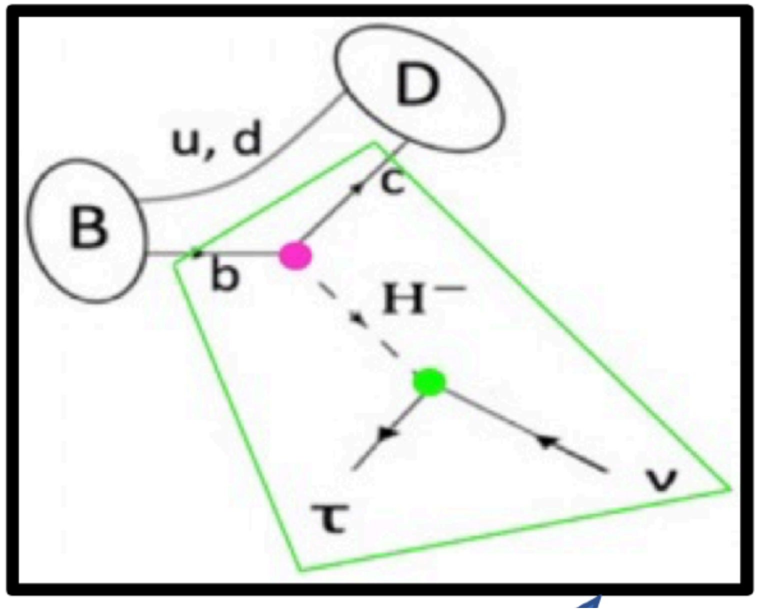
- $\frac{|V_{ub}|}{|V_{cb}|} = 0.079 \pm 0.006$ (from $\frac{\Gamma(\Lambda_b \to p\mu\nu)}{\Gamma(\Lambda_b \to \Lambda_c\mu\nu)}$ [LHCb 1504.01568])



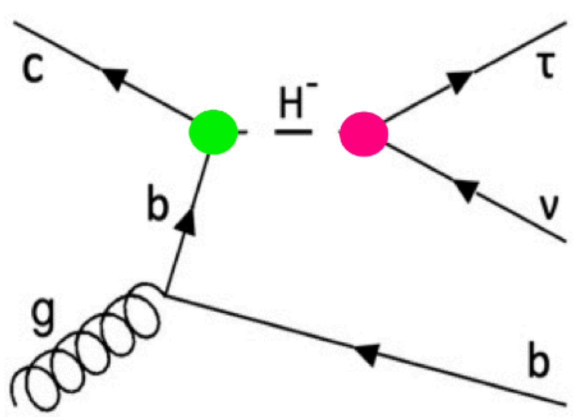
Mode(s)	Inputs	χ^2_{min}/DOF	$\|V_{ub}\| \times 10^3$	$\|V_{cb}\| \times 10^3$	$\frac{\|V_{ub}\|}{\|V_{cb}\|}$	Correlation (%) $[\|V_{ub}\|, \|V_{cb}\|]$
$\bar{B} \to \pi l^- \bar{\nu}$ and $b \to c l^- \bar{\nu}$	Experiment+ All Lattice	171.1/156	3.61 ± 0.15	40.4 ± 0.6	0.089 ± 0.004	12.8
	Experiment+All Lattice+LCSR	191.7/167	3.43 ± 0.12	40.4 ± 0.6	0.085 ± 0.003	14.1
	Experiment+ All Lattice +LCSR (without $f_+^{B_s \to K}$)	176.1/166	3.57 ± 0.13	40.3 ± 0.6	0.089 ± 0.003	11.5
$b \to c l^- \bar{\nu}$, $b \to u l^- \bar{\nu}$	Experiment+Lattice+LCSR	231.8/225	3.34 ± 0.10	40.4 ± 0.6	0.083 ± 0.003	12.4
	Experiment+ All Lattice +LCSR (without $f_+^{B_s \to K}$)	219.5/224	3.51 ± 0.11	40.2 ± 0.6	0.087 ± 0.003	10.4

Global fit to $b \to c\tau\nu$

Syuhei Iguro



Reinterpreting the CMS (36/fb) $\tau\nu$ resonance search excludes charged Higgs with $m_{H^+} > 400$ GeV



Q: What about $m_{H^+} < 400$ GeV?

A: b-tagging suppresses the SM background and may help shrink the window

Summary of model prediction: correlation

Relaxed $B_c \to \tau\nu$ bound and shifted $R_{D^{(*)}}$ — 2210.10751 (v3 soon)

		Spin	Charge	Operators	R_D	R_{D^*}	LHC	Flavor
	$H^\pm$	0	$(\mathbf{1},\mathbf{2},1/2)$	O_{S_L}	✓	✓	$b\tau\nu$	$B_c \to \tau\nu$, $F_L^{D^*}$, P_τ^D, M_W
LQ	S_1	0	$(\bar{\mathbf{3}},\mathbf{1},1/3)$	O_{V_L}, O_{S_L}, O_T	✓	✓	$\tau\tau$	ΔM_s, P_τ^D, $B \to K^{(*)}\nu\nu$
LQ	$R_2^{(2/3)}$	0	$(\mathbf{3},\mathbf{2},7/6)$	O_{S_L}, O_T, (O_{V_R})	✓	✓	$b\tau\nu$, $\tau\tau$	$R_{\Upsilon(nS)}$, $P_\tau^{D^*}$, M_W
LQ	U_1	1	$(\mathbf{3},\mathbf{1},2/3)$	O_{V_L}, O_{S_R}	✓	✓	$b\tau\nu$, $\tau\tau$	$R_{K^{(*)}}$, $R_{\Upsilon(nS)}$, $B_s \to \tau\tau$
LQ	$V_2^{(1/3)}$	1	$(\bar{\mathbf{3}},\mathbf{2},5/6)$	O_{S_R}	✓	2σ	$\tau\tau$	$B \to \tau\nu$, $B_s \to \tau\tau$, $B \to K\tau\tau$

See also Angelescu et al, 2103.12504, Athron et al 2104.03691 for the previous version of LQs

$\text{Pull} \equiv \sqrt{\chi^2_{\rm SM} - \chi^2_{\text{NP-best}}}\ (\sigma)$

based on $R_{D^{(*)}}$, $F_L^{D^*}$

$\mu_b = \mu$

$C_{S_L} = -0.88 \pm 0.88i$	Pull=4.3σ	$H^\pm$
$C_{S_L} = -8.9 C_T = 0.19$	Pull=3.9σ	S_1
$C_{S_L} = 8.4 C_T = -0.07 \pm 0.58i$	Pull=4.0σ	R_2
$C_{V_L} = 0.07 = C_{S_R}/(-3.7)\times e^{-i\phi_R}$, $\phi_R = 0.54\pi$	Pull=4.1σ	U_1
$C_{S_R} = -0.2$	Pull=3.8σ	V_2

Similar goodness of fit

Model discrimination is possible via these correlated predictions

Also, τ polarization in $B \to D^{(*)}\tau\nu$ is important @ Belle II

6

Sensitivity in other observables/systems?

- **All NP models → LHC study**
- **Charged Higgs → contributes to $b \to s\ell\ell$ via C_9**
- **$U(1)$ leptoquark → connection to EDM**

Impact of $\Lambda_b \to \Lambda_c \tau \nu$ on New Physics in $b \to c\tau\nu$ transitions

Marco Fedele

Update of the sum rule

As a first step, we updated the sum rules due to update in $B \to D^*$ FF

$$\frac{\mathcal{R}(\Lambda_c)}{\mathcal{R}_{\rm SM}(\Lambda_c)} = 0.280\,\frac{\mathcal{R}(D)}{\mathcal{R}_{\rm SM}(D)} + 0.720\,\frac{\mathcal{R}(D^*)}{\mathcal{R}_{\rm SM}(D^*)} + \delta_{\Lambda_c}$$

$$\mathcal{R}(\Lambda_c) \simeq \mathcal{R}_{\rm SM}(\Lambda_c)\left(0.280\,\frac{\mathcal{R}(D)}{\mathcal{R}_{\rm SM}(D)} + 0.720\,\frac{\mathcal{R}(D^*)}{\mathcal{R}_{\rm SM}(D^*)}\right)$$

$$= \mathcal{R}_{\rm SM}(\Lambda_c)(1.172 \pm 0.038)$$

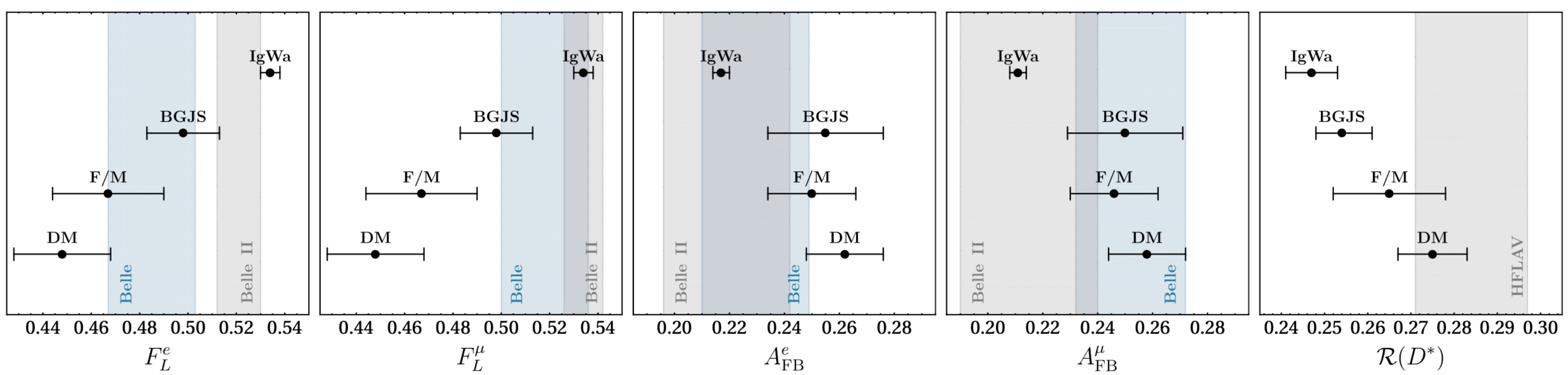
$$= 0.380 \pm 0.012 \pm 0.005$$

to be compared with

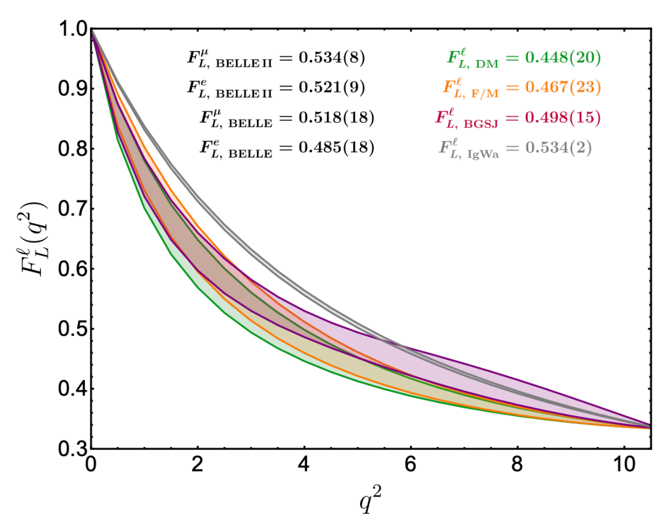
$$R(\Lambda_c)_{\rm exp} = 0.242 \pm 0.076$$

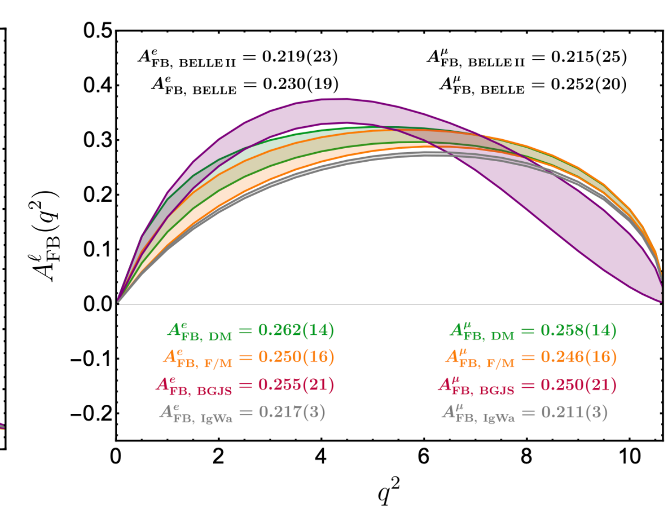
$$R(\Lambda_c)_{\rm exp'} = (0.285 \pm 0.073)\left|\frac{0.04}{V_{cb}}\right|^2$$

Not all that glitters is gold…



The DM FF approach is capable to address tension in $R(D^*)$ (and $|V_{cb}|$ incl. vs excl. discrepancy), but <u>however</u> in tension with new F_L^ℓ and $A_{\rm FB}^\ell$ data!





2305.15457
MF, Blanke, Crivellin, Iguro, Nierste, Simula, Vittorio

Toward a summary

Some impressions - Experimental measurements

- CMS starting to use parked data to add LFU to existing program. Proof of concept now, but will improve steadily with time.
- Belle II first $R(D^{\star})$, Belle II first measurement of $R_{\tau/\ell}(X)$ at a b-factory
- Move toward differential measurements / studying full angular dependence
- Marcelo - multi-hadron final states
- Additional precise measurements of familiar quantities [e.g., $R(D)$]

Toward a summary

Some impressions - Lattice QCD

- $B \to D^{(\star)}\ell\nu$: Major progress since last CKM: new calculations of form factors for at nonzero recoil from Fermilab-MILC, HPQCD, and JLQCD
- Updated calculations are underway for many channels: $B \to D^{(\star)}$, $B \to \pi/K$
- Frontiers of lattice QCD include:
  - Multi-hadron final states, e.g., $B \to \rho\ell\nu$
  - Inclusive SL decays

Toward a summary

Some impressions - HQET

- Progress toward extending to higher orders, including
  - Partonic $\mathcal{O}(\alpha_s^3)$ corrections (Matteo Fael)
  - Subleading $\mathcal{O}(\alpha_s \rho_D)$ corrections (Daniel Moreno)
  - Effects of New Physics operators
- New ideas about constraining non-perturbative inputs
  - Residual chiral expansion
  - RPI quantities → New determination of $|V_{cb}|^{incl}_{q^2}$

Toward a summary

Some impressions - Combined analyses

- Vibrant effort to synthesis our best knowledge of experimental and theoretical quantities
  - Combining lattice QCD form factors
  - Combining lattice-QCD and LCSR form factors
  - Global fits to theoretical results and experimental measurements
  - Exploiting the constrains of analyticity and unitarity