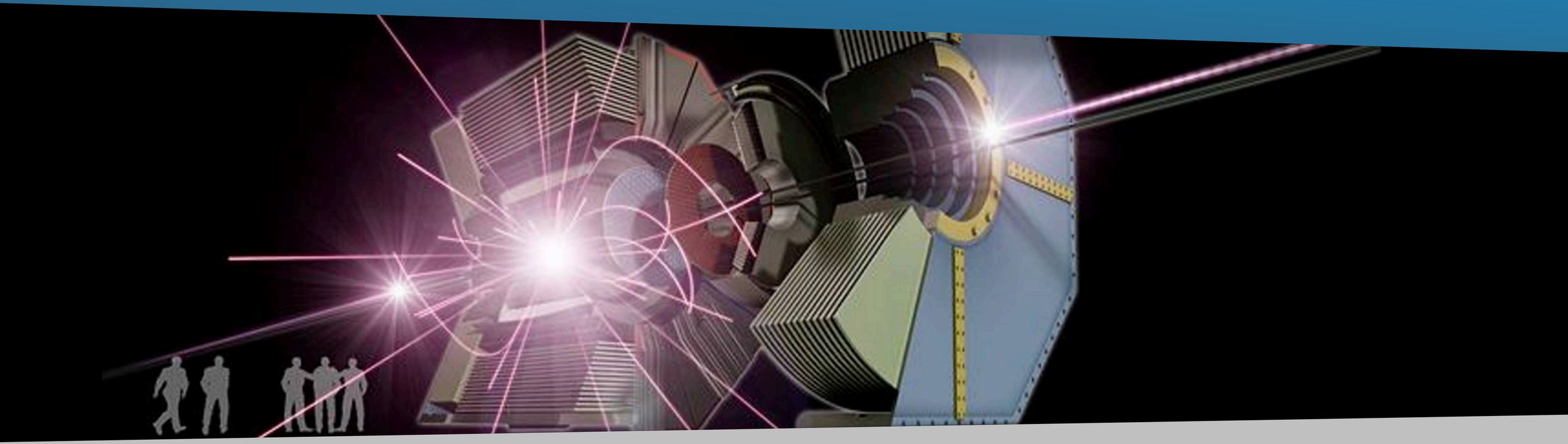
Measurements of $|V_{cb}|$ and $|V_{ub}|$ from Belle (II)



Lu Cao

(for the Belle & Belle II Collaboration)

BEAUTY 2023 @ Clermont-Ferrand

Content

Measurements covered in this talk:

Exclusive $|V_{cb}|$:

- Had. tagged $B^0 \to D^* \ell \nu$
- Had. tagged $B \to D^* \ell \nu$ and shapes of key kinematic variables

Exclusive $|V_{ub}|$:

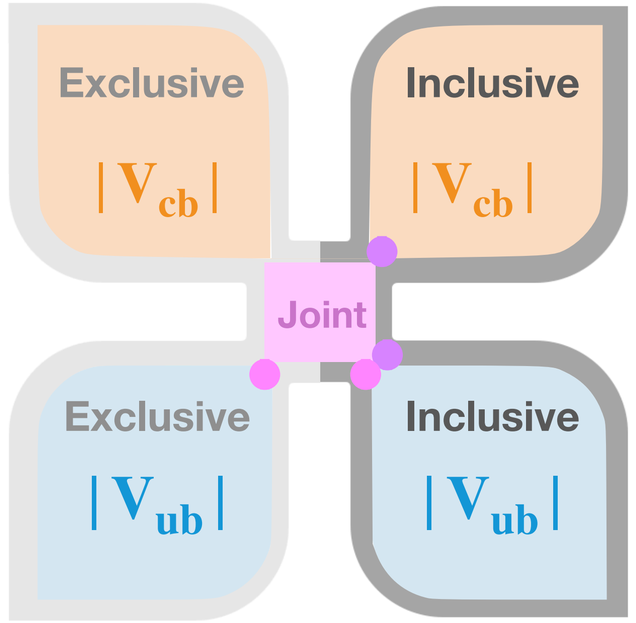
- Untagged $B^0 \to \pi^- \ell \nu$

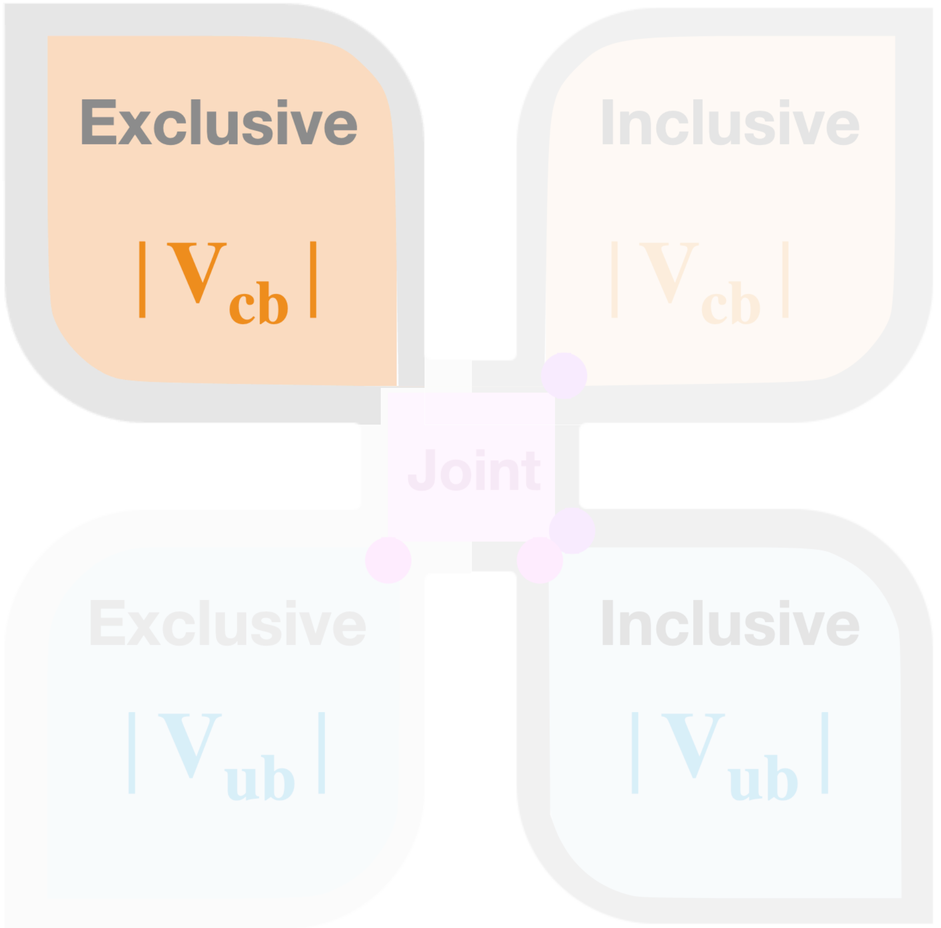
Inclusive $|V_{ub}|$:

- Partial & differential branching fractions of $B \to X_u \ell \nu$

Combined measurements:

- Excl. $|V_{ub}|$ / incl. $|V_{ub}|$
- Incl. $|V_{ub}|$ / incl. $|V_{cb}|$

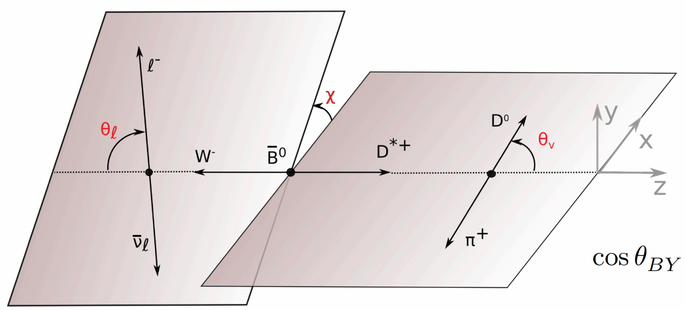



Exclusive
$|V_{cb}|$
Inclusive
$|V_{cb}|$
Joint
Exclusive
$|V_{ub}|$
Inclusive
$|V_{ub}|$

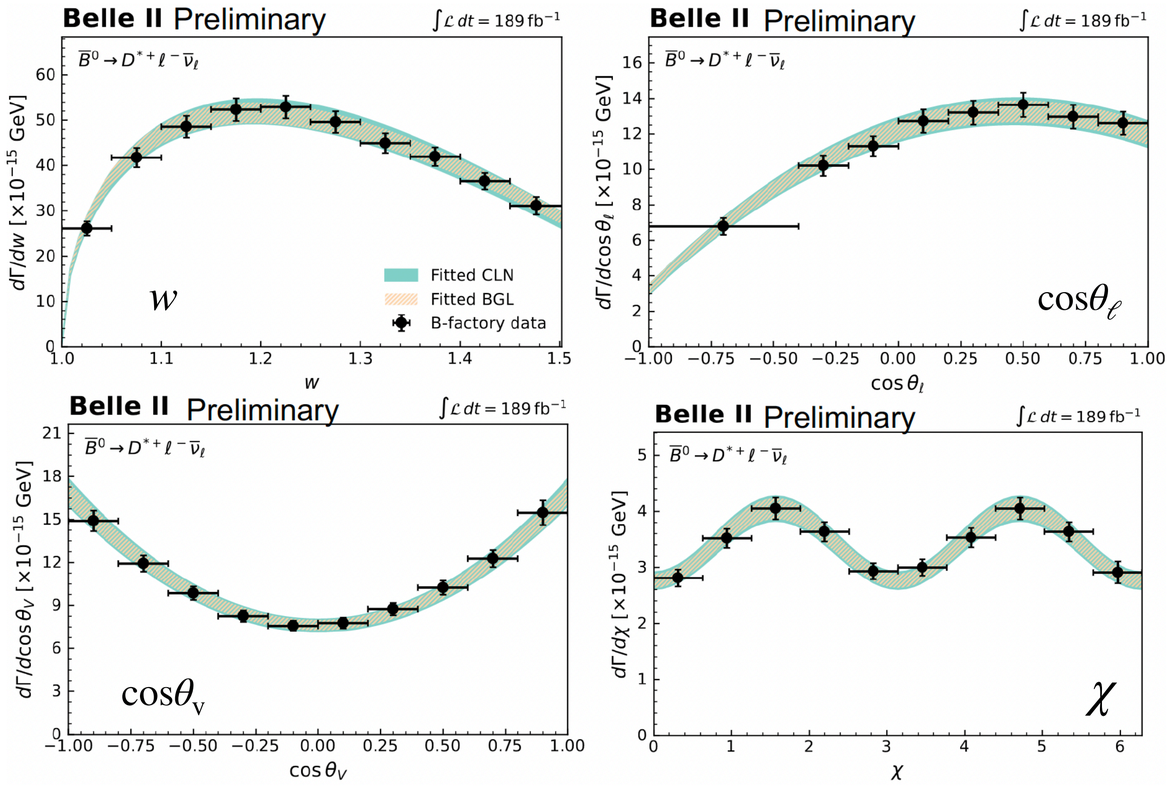
Branching Fraction of $B^0 \to D^*\ell\nu$ and $|V_{cb}|$

Preliminary

- Data set of 189.3 fb^{-1} with untagged strategy (higher efficiency than tagged)
- Decay chain: **$B^0 \to D^{*+}\ell\nu$, $D^{*+} \to D^0\pi^+_{slow}$, $D^0 \to K^-\pi^+$**
- 2D fit on ($\cos\theta_{BY}$, $\Delta M = M(D^{*+}) - M(D^0)$) for each bin of **w**, **$\cos\theta_\ell$**, **$\cos\theta_V$**, χ
- Unfold signal yields and correct efficiency & acceptance
- Full experimental correlations derived for all measured decay rates



$$\cos\theta_{BY} = \frac{2E_B^{\rm CM}E_Y^{\rm CM} - m_B^2 - m_Y^2}{2|\vec{p}_B^{\rm CM}||\vec{p}_Y^{\rm CM}|}$$



reco. eff & acc. — input of PDG2022

$$\Delta\Gamma_i = \frac{y_i^{\rm unfolded}}{\epsilon_i N_{B^0} \mathcal{B}(D^{*+} \to D^0\pi^+)\mathcal{B}(D^0 \to K^-\pi^+)\tau_{B^0}}$$

$$\Gamma = \left(\sum_{i=1}^{10}\Delta\Gamma_i^w + \sum_{i=1}^{8}\Delta\Gamma_i^{\cos\theta_\ell} + \sum_{i=1}^{10}\Delta\Gamma_i^{\cos\theta_V} + \sum_{i=1}^{10}\Delta\Gamma_i^{\chi}\right)/4$$

Branching fraction extracted by the **total rate** summing over partial decay rates and averaging all kin. variables

Preliminary

e mode: $\mathcal{B}(\bar{B}^0 \to D^{*+}e^-\bar{\nu}_e) = (4.94 \pm 0.03 \pm 0.22)\%$

μ mode: $\mathcal{B}(\bar{B}^0 \to D^{*+}\mu^-\bar{\nu}_\mu) = (4.94 \pm 0.03 \pm 0.24)\%$

Average: $\mathcal{B}(\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell) = (4.94 \pm 0.02 \pm 0.22)\%$

Branching Fraction of $B^0 \to D^* \ell \nu$ and $|V_{cb}|$

Preliminary

- Fit differential shapes on w, $\cos\theta_\ell$, $\cos\theta_v$, χ with **Caprini-Lellouch-Neubert (CLN)** [Nucl. Phys. B530, 153] & **Boyd-Grinstein-Lebed (BGL) parameterisations** [Phys. Rev. D56, 6895)]
- BGL truncation based on nested hypothesis test[Phys. Rev. D100, 013005]
- Inclusion of LQCD constraint [Eur. Phys. J. C 82, 1141 (2022)] at beyond zero-recoil (w = [1.03, 1.10, 1.17]) in two scenarios

$$|V_{cb}|\eta_{\rm EW}\mathcal{F}(1) = \frac{1}{\sqrt{m_B m_{D^*}}}\left(\frac{|\tilde{b}_0|}{P_f(0)\phi_f(0)}\right)$$

$$|V_{cb}|_{\rm BGL} = (40.9 \pm 0.3 \pm 1.0 \pm 0.6) \times 10^{-3}$$

$$|V_{cb}|_{\rm CLN} = (40.4 \pm 0.3 \pm 1.0 \pm 0.6) \times 10^{-3}$$

Preliminary

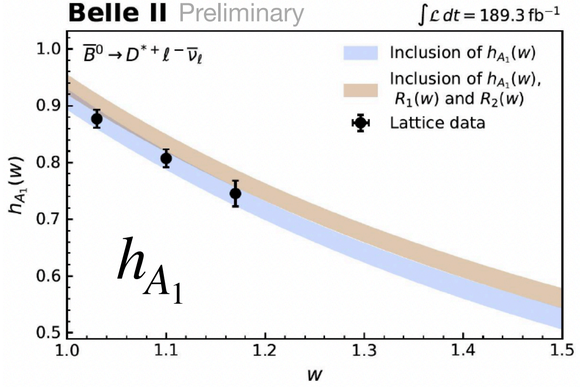
Slow pion eff. plays leading role in syst.

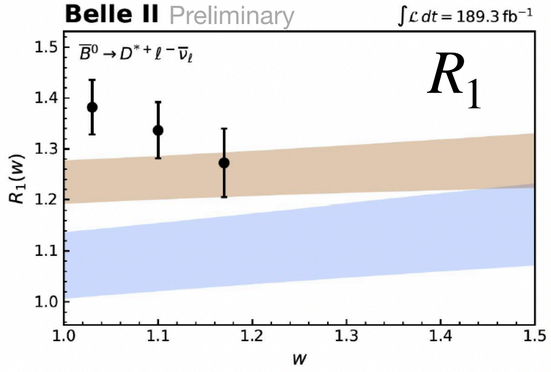
Input from LQCD at zero-recoil F(1)

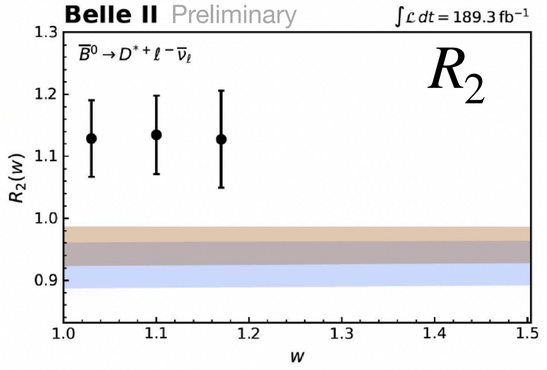
BGL	Constraints on $h_{A_1}(w)$	Constraints on $h_{A_1}(w)$, $R_1(w)$, $R_2(w)$
$a_0 \times 10^3$	21.7 ± 1.4	25.7 ± 0.8
$b_0 \times 10^3$	13.20 ± 0.24	13.58 ± 0.23
$b_1 \times 10^3$	-7 ± 7	2 ± 6
$c_1 \times 10^3$	-1.1 ± 0.8	-0.5 ± 0.8
$\lvert V_{cb}\rvert \times 10^3$	40.5 ± 1.2	38.6 ± 1.1
χ^2/ndf	40/33	74/39
p-value	0.18	0.001

Preliminary

$|V_{cb}|$ shifts when include full LQCD constraints







Similar tension seen in recent Belle (2023) measurement [arXiv:2301.07529]

⇒ Both found large disagreements wrt LQCD results on R_2

Branching Fraction of $B^0 \to D^* \ell \nu$ and $|V_{cb}|$

Preliminary

- Lepton-flavor-universality tested with separate results on e- & mu-mode
- All in **good agreement with SM expectations**

Test on branching fraction ratio: $R_{e/\mu} = 1.001 \pm 0.009 \pm 0.021$

Preliminary

SM prediction	PRD 106, 096015	EPJC 81, 984
$R_{e/\mu}$	1.0041 ± 0.0001	1.0026 ± 0.0001
$\mathcal{A}_{\rm FB}^e$	0.244 ± 0.004	0.204 ± 0.012
$\mathcal{A}_{\rm FB}^\mu$	0.239 ± 0.004	0.198 ± 0.012
$\Delta\mathcal{A}_{\rm FB} \times 10^3$	-5.7 ± 0.1	-5.33 ± 0.24
F_L^e	0.516 ± 0.003	0.541 ± 0.011
F_L^μ	0.516 ± 0.003	0.542 ± 0.012
$\Delta F_L \times 10^4$	1.2 ± 0.1	5.43 ± 0.36

Test on forward-backward asymmetry:

$$\mathcal{A}_{\rm FB} = \frac{\int_0^1 \mathrm{d}\cos\theta_\ell \mathrm{d}\Gamma/\mathrm{d}\cos\theta_\ell - \int_{-1}^0 \mathrm{d}\cos\theta_\ell \mathrm{d}\Gamma/\mathrm{d}\cos\theta_\ell}{\int_0^1 \mathrm{d}\cos\theta_\ell \mathrm{d}\Gamma/\mathrm{d}\cos\theta_\ell + \int_{-1}^0 \mathrm{d}\cos\theta_\ell \mathrm{d}\Gamma/\mathrm{d}\cos\theta_\ell}$$

$$\Delta\mathcal{A}_{\rm FB} = \mathcal{A}_{\rm FB}^\mu - \mathcal{A}_{\rm FB}^e$$

Preliminary

$$\mathcal{A}_{\rm FB}^e = 0.219 \pm 0.011 \pm 0.020\,,$$
$$\mathcal{A}_{\rm FB}^\mu = 0.215 \pm 0.011 \pm 0.022\,,$$
$$\boxed{\Delta\mathcal{A}_{\rm FB} = (-4 \pm 16 \pm 18) \times 10^{-3}}$$

Test on D* longitudinal polarization fraction:

$$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta_V} = \frac{3}{2}\left(F_L \cos^2\theta_V + \frac{1-F_L}{2}\sin^2\theta_V\right)$$

$$\Delta F_L = F_L^\mu - F_L^e$$

Preliminary

$$F_L^e = 0.521 \pm 0.005 \pm 0.007$$
$$F_L^\mu = 0.534 \pm 0.005 \pm 0.006$$
$$\boxed{\Delta F_L = 0.013 \pm 0.007 \pm 0.007}$$

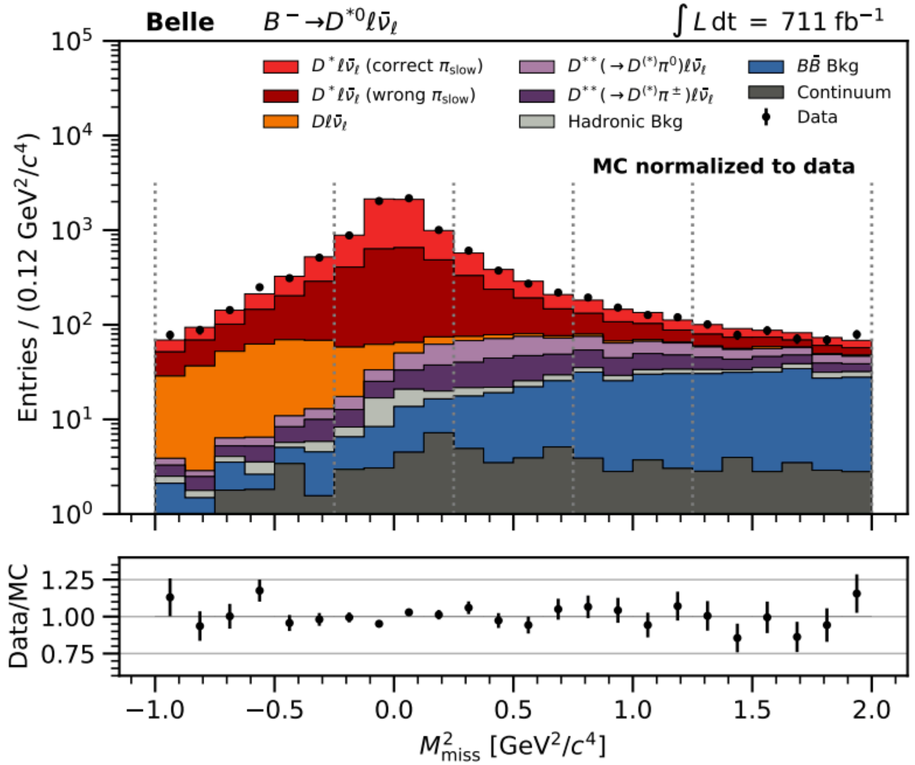
$|V_{cb}|$ & Differential Shapes of $B \to D^* \ell \nu$

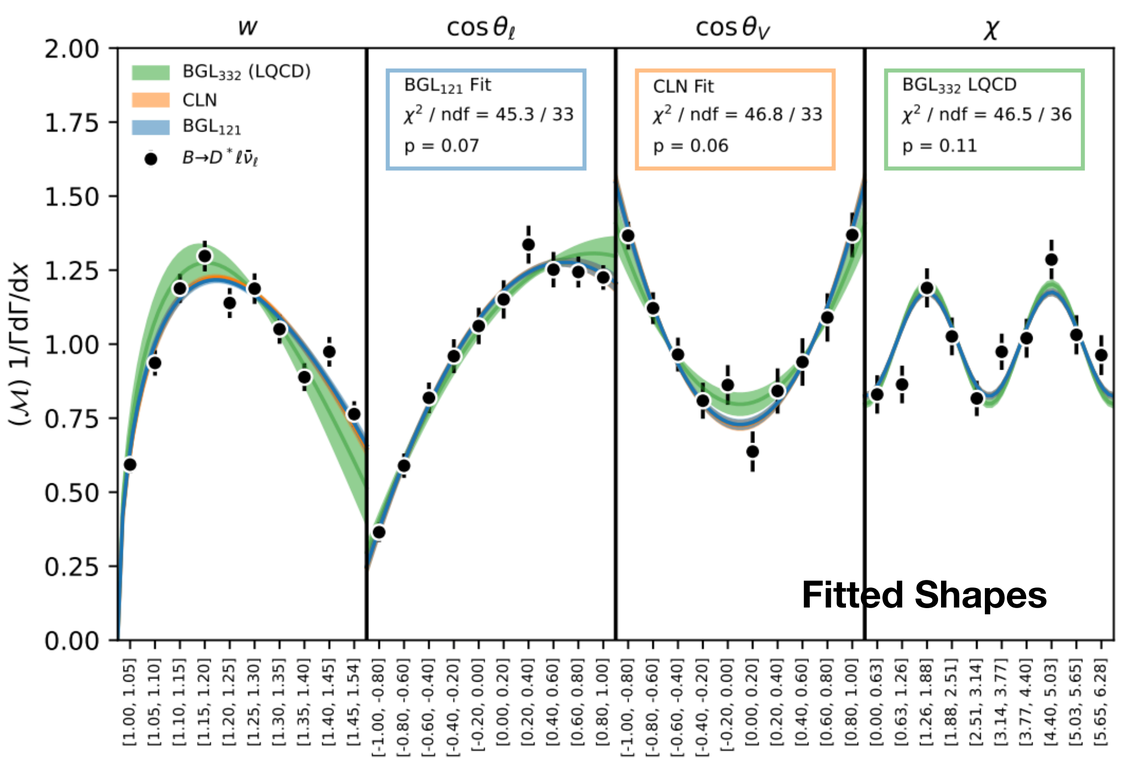
arXiv: 2301.07529

accepted by PRD

- Full Belle data set of 711 fb^{-1} for $B^{\pm,0}, \ell = e, \mu$
- **Hadronic tagging** using Belle II tool (Full Event Interpretation [Comp. Soft. Big Sci 3 (2019) 6])
- Background subtracted via fitting $M^2_{\rm miss}$ for bins of $w, \cos\theta_\ell, \cos\theta_V, \chi$ in **each decay mode independently**
- Combined **all kin. shapes** to extract $|V_{cb}|$ in **BGL/CLN** with external constraints on **branching fractions** (HFLAV) and **LQCD** (FNAL/MILC)

Eur. Phys. J. C 82, 1141 (2022)





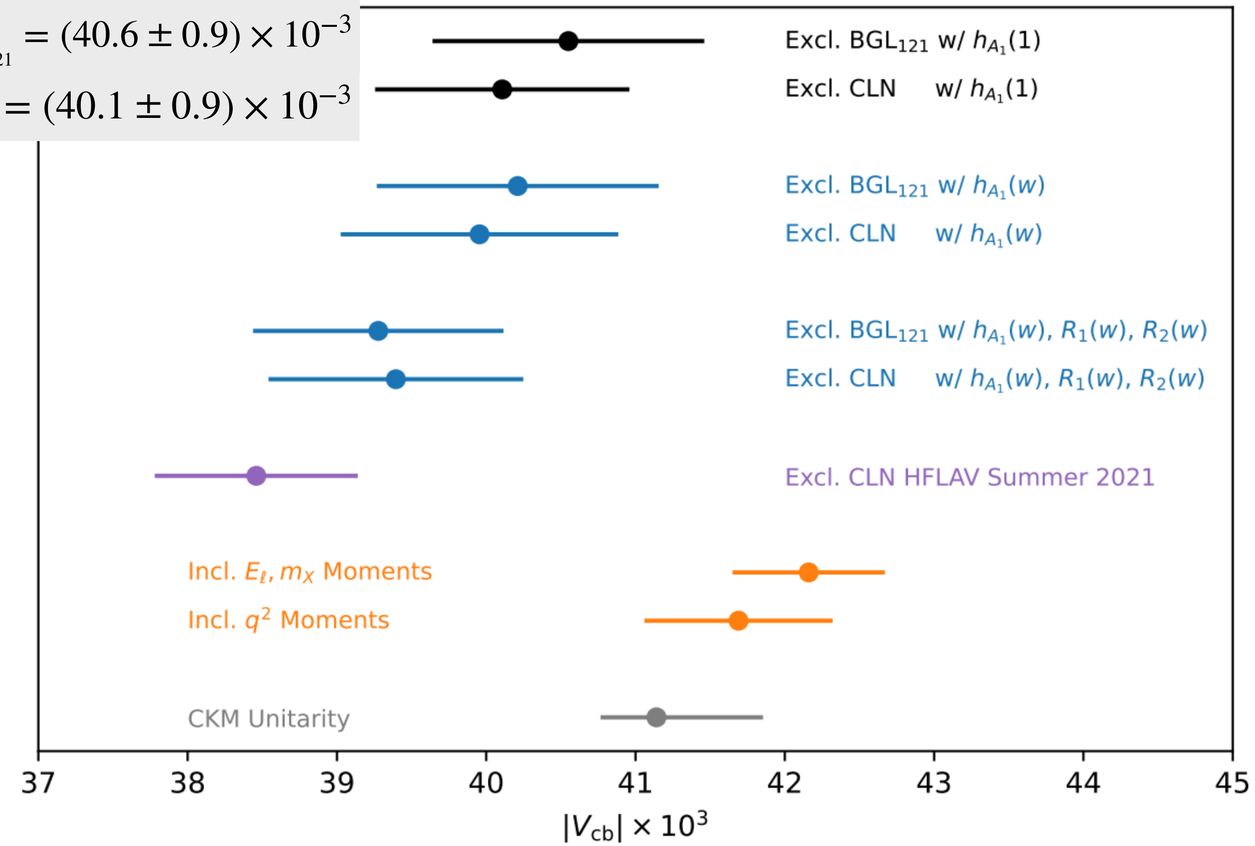
$|V_{cb}|$ & Differential Shapes of $B \to D^* \ell \nu$

- In $|V_{cb}|$ extraction, tested different BGL truncations, LQCD constraining scenario (at or beyond zero-recoil)
- **Forward-backward asymmetry A_{FB}** and **D* longitudinal polarization fraction $F_L^{D^*}$** and their differences between e, μ also derived. **No significant LFUV found.**

arXiv: 2301.07529

accepted by PRD

$$|V_{cb}|_{\mathrm{BGL}_{121}} = (40.6 \pm 0.9) \times 10^{-3}$$
$$|V_{cb}|_{\mathrm{CLN}} = (40.1 \pm 0.9) \times 10^{-3}$$

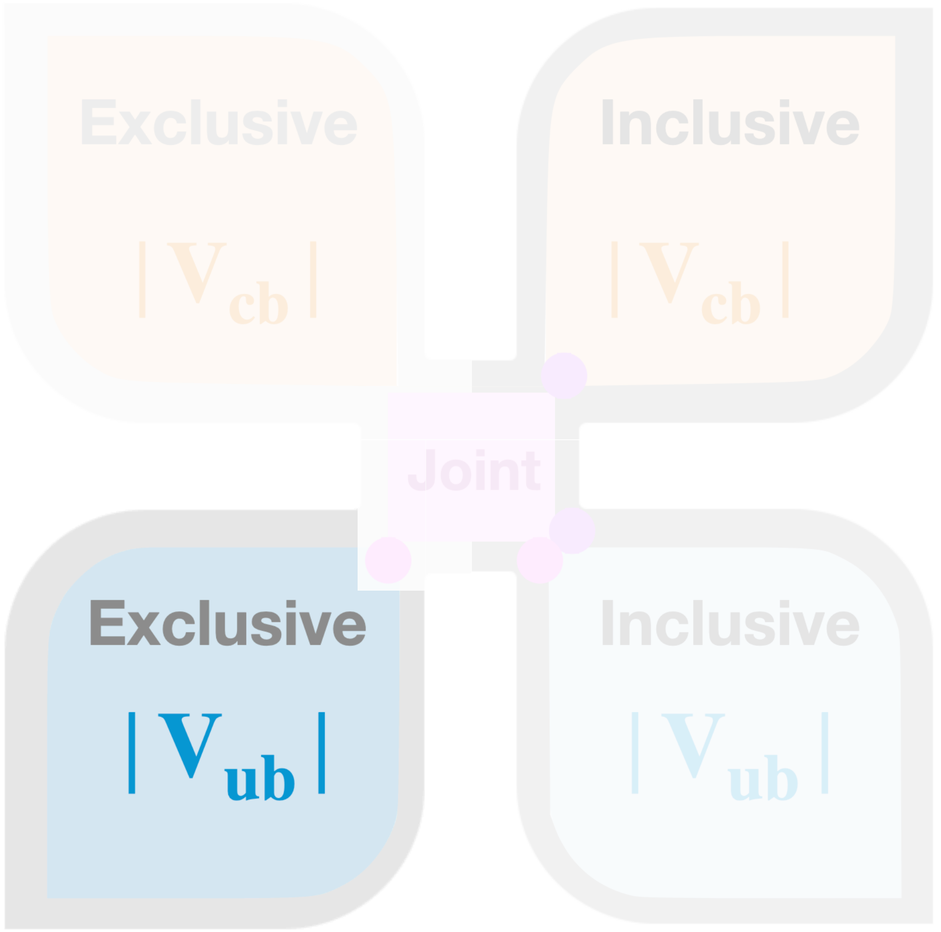


$$A_{\mathrm{FB}} = \frac{\int_0^1 \mathrm{d}\cos\ell\, \mathrm{d}\Gamma/\mathrm{d}\cos\ell - \int_{-1}^0 \mathrm{d}\cos\ell\, \mathrm{d}\Gamma/\mathrm{d}\cos\ell}{\int_0^1 \mathrm{d}\cos\ell\, \mathrm{d}\Gamma/\mathrm{d}\cos\ell + \int_{-1}^0 \mathrm{d}\cos\ell\, \mathrm{d}\Gamma/\mathrm{d}\cos\ell}$$

	ΔA_{FB}
$\bar{B}^0 \to D^{*+} \ell \bar{\nu}_\ell$	$0.062 \pm 0.044 \pm 0.011$
$B^- \to D^{*0} \ell \bar{\nu}_\ell$	$-0.003 \pm 0.033 \pm 0.009$
$B \to D^* \ell \bar{\nu}_\ell$	$0.022 \pm 0.026 \pm 0.007$

$$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta_V} = \frac{3}{2}\left(F_L \cos^2\theta_V + \frac{1-F_L}{2}\sin^2\theta_V\right)$$

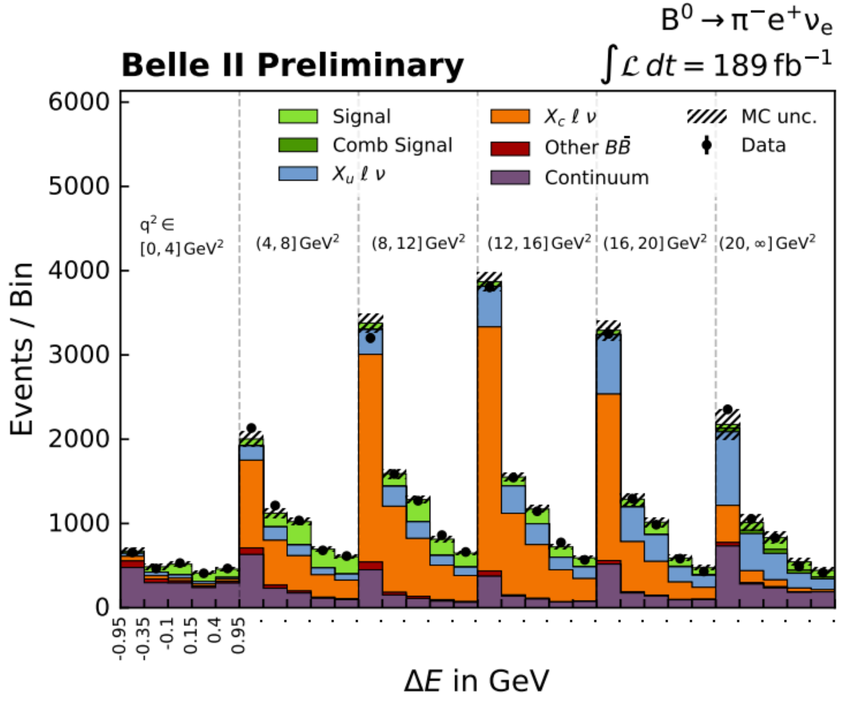
	$\Delta F_L^{D^*}$
$\bar{B}^0 \to D^{*+} \ell \bar{\nu}_\ell$	$0.032 \pm 0.033 \pm 0.010$
$B^- \to D^{*0} \ell \bar{\nu}_\ell$	$0.025 \pm 0.035 \pm 0.010$
$B \to D^* \ell \bar{\nu}_\ell$	$0.034 \pm 0.024 \pm 0.007$

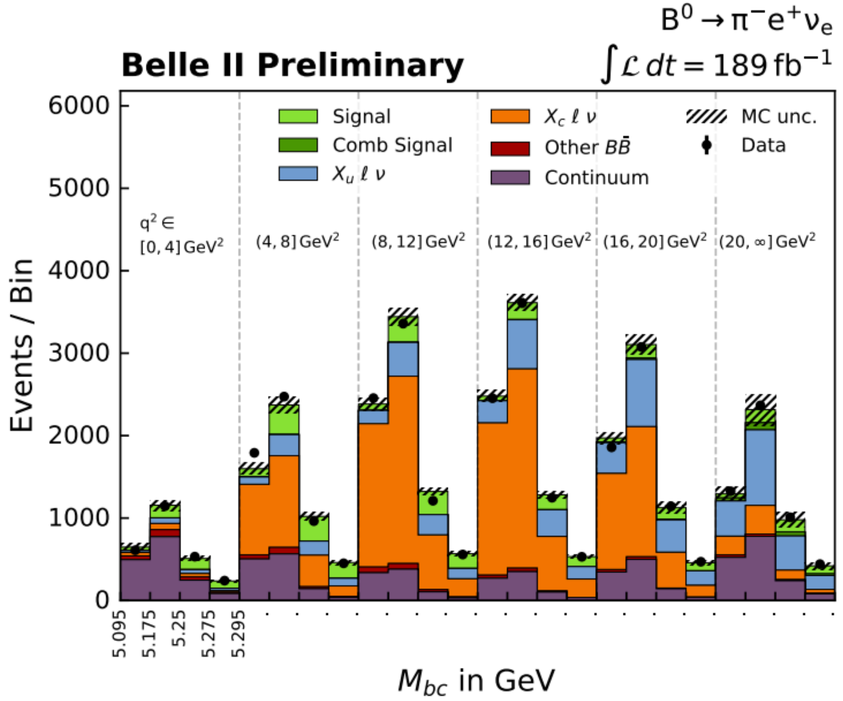

Exclusive
$|V_{cb}|$
Inclusive
$|V_{cb}|$
Joint
Exclusive
$|V_{ub}|$
Inclusive
$|V_{ub}|$

$|V_{ub}|$ in $B^0 \to \pi^- \ell^+ \nu$ Decay

arXiv: 2210.04224

- Data set of 189.3 fb^{-1} with untagged analysis strategy
- Extract signal in beam-constrained mass M_{bc} and energy difference ΔE for each bin of q^2
- $|\mathbf{V_{ub}}|$ fitted with Bourrely-Caprini-Lellouch (**BCL**) [Phys.Rev.D79, 013008] expansion including **LQCD** constraints (FNAL/MILC [Phys. Rev. D92, 014024])





$$\Delta E = E_B^* - E_{\text{beam}}^* = E_B^* - \frac{\sqrt{s}}{2}$$

$$M_{bc} = \sqrt{E_{\text{beam}}^{*2} - |\vec{p}_B^{\,*}|^2} = \sqrt{\left(\frac{\sqrt{s}}{2}\right)^2 - |\vec{p}_B^{\,*}|^2}$$

$|V_{ub}|$ in $B^0 \to \pi^- \ell^+ \nu$ Decay

arXiv: 2210.04224

- Data set of 189.3 fb^{-1} with untagged analysis strategy
- Extract signal in beam-constrained mass M_{bc} and energy difference ΔE for each bin of q^2
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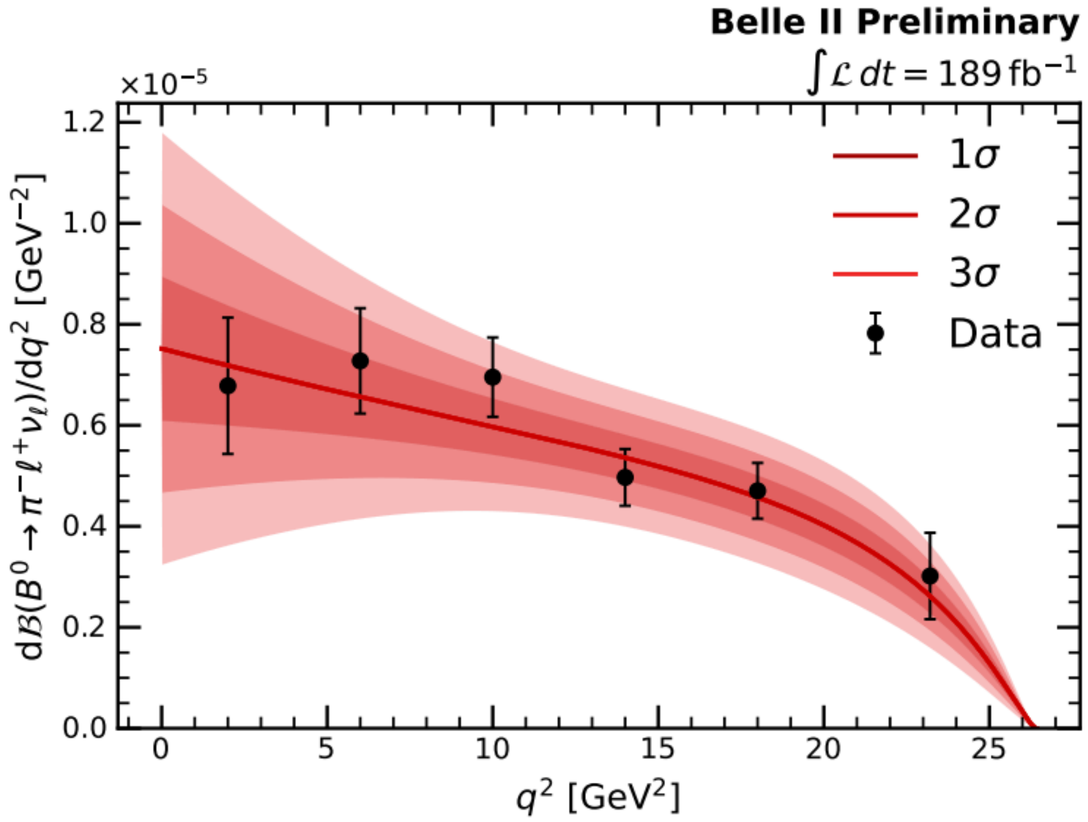


$$\mathcal{B} = (1.426 \pm 0.056_{\text{stat}} \pm 0.125_{\text{syst}}) \times 10^{-4}$$

$$|V_{ub}| = (3.55 \pm 0.12_{\text{stat}} \pm 0.13_{\text{syst}} \pm 0.17_{\text{theo}}) \times 10^{-3}$$

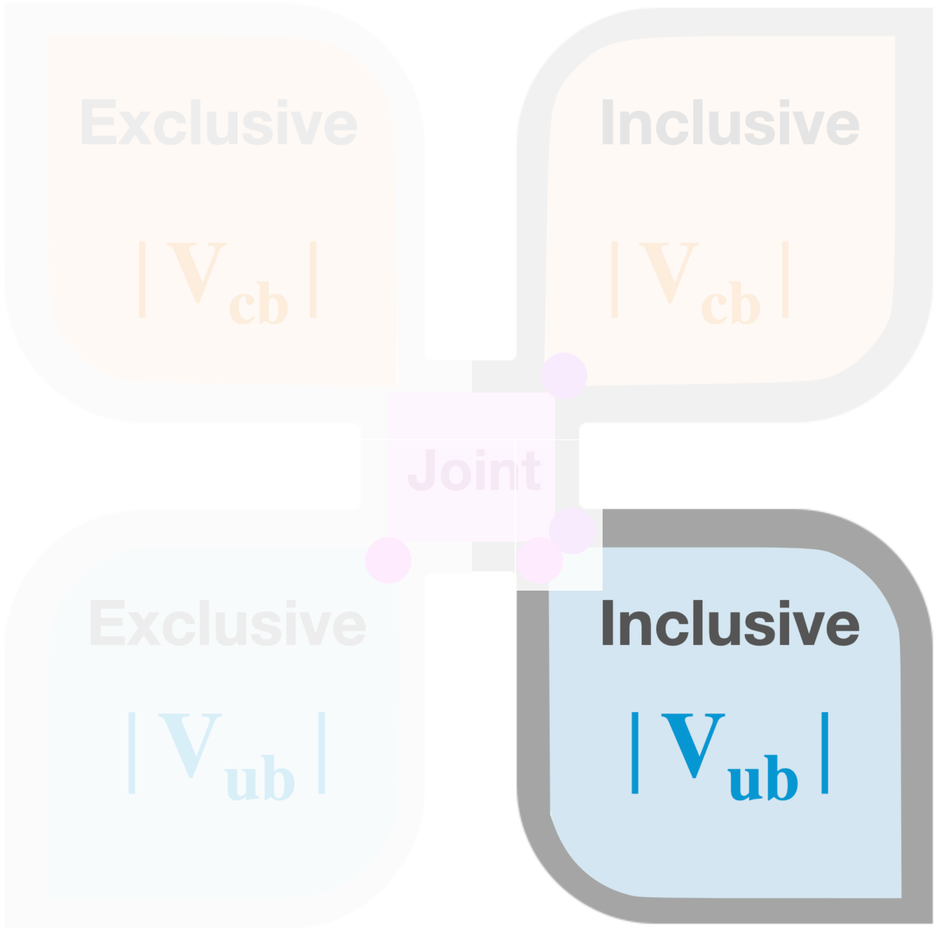
dominated by background modelling (continuum, $B \to \rho \ell \nu$)

Recent Belle II Results on Exclusive $|V_{xb}|$

	$\|V_{cb}\| \times 10^3$	References
$B^0 \to D^{*-}\ell^+\nu$, untagged	**40.9 ± 1.2 (BGL)**	To be submitted to PRD
$B^0 \to D^{*-}\ell^+\nu$, tagged	**37.9 ± 2.7 (CLN)**	arXiv:2301.04716
$B \to D\ell\nu$, untagged	**38.28 ± 1.16 (BGL)**	arXiv:2210.13143
	$\|V_{ub}\| \times 10^3$	References
$B \to \pi e\nu$, tagged	**3.88 ± 0.45**	arXiv:2206.08102
$B \to \pi\ell\nu$, untagged	**3.55 ± 0.25**	arXiv:2210.04224

HFLAV 2023

$$|V_{cb}|_{\text{excl}} = (39.10 \pm 0.50) \times 10^{-3}$$
$$|V_{ub}|_{\text{excl}} = (3.51 \pm 0.12) \times 10^{-3}$$


Exclusive
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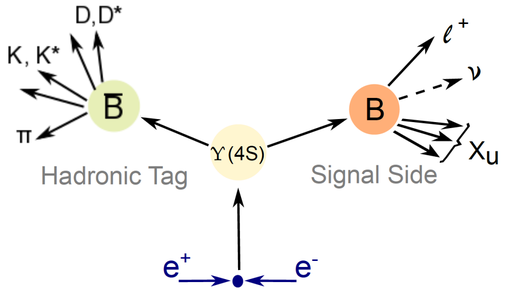
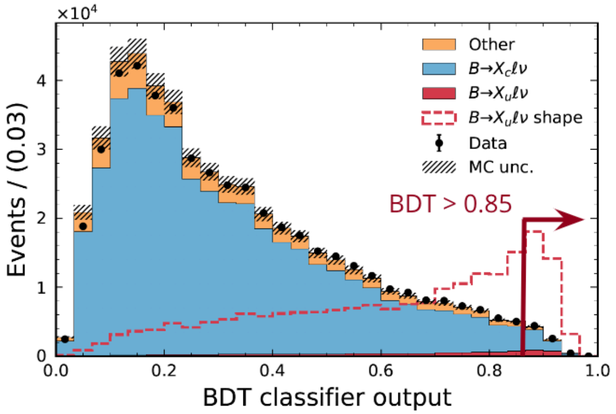
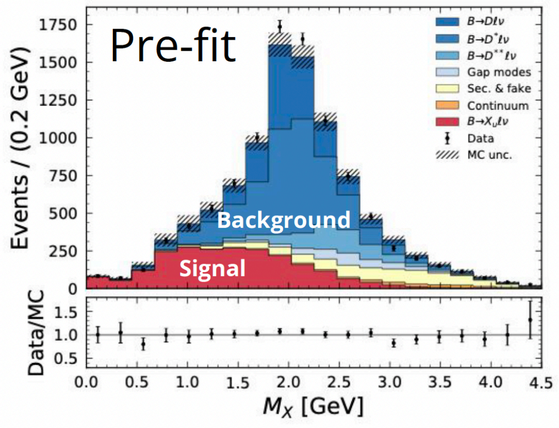
Inclusive $B \to X_u \ell \nu$ and $|V_{ub}|$

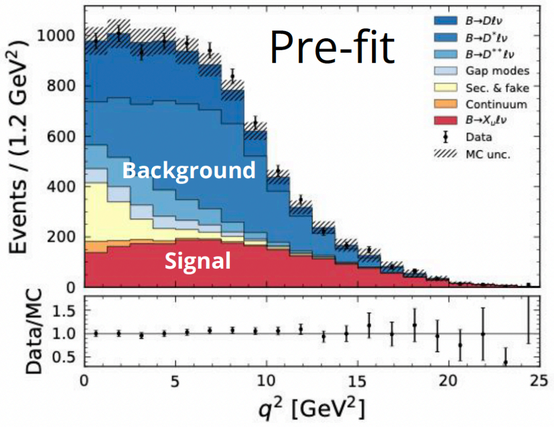
PRD 104 , 012008 (2021)

- Full Belle data set of 711 fb^{-1} with **Hadronic tagging**
- Use **machine learning (BDT)** to suppress backgrounds with 11 training features, e.g. MM^2,#K$^{\pm}$, #K$_s$, etc.





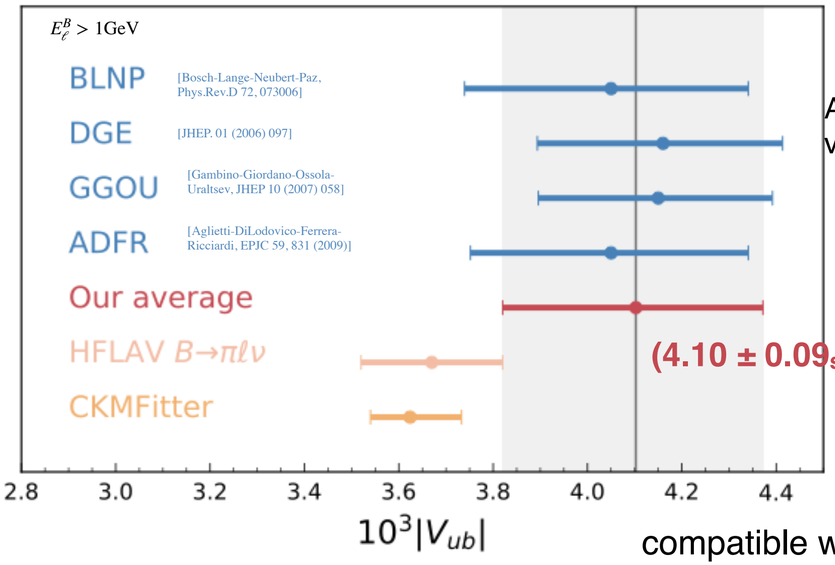




- Partial BF and inclusive $|V_{ub}|$ derived in various phase space regions

$$\Delta\mathcal{B}(E_\ell^B > 1\text{GeV}) = (1.59 \pm 0.07 \pm 0.16) \times 10^{-3}$$

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(B \to X_u \ell \nu)}{\tau_B \cdot \Delta\Gamma(B \to X_u \ell \nu)}}$$



Arithmetic avr. $|V_{ub}|$ based on various theo. decay rate

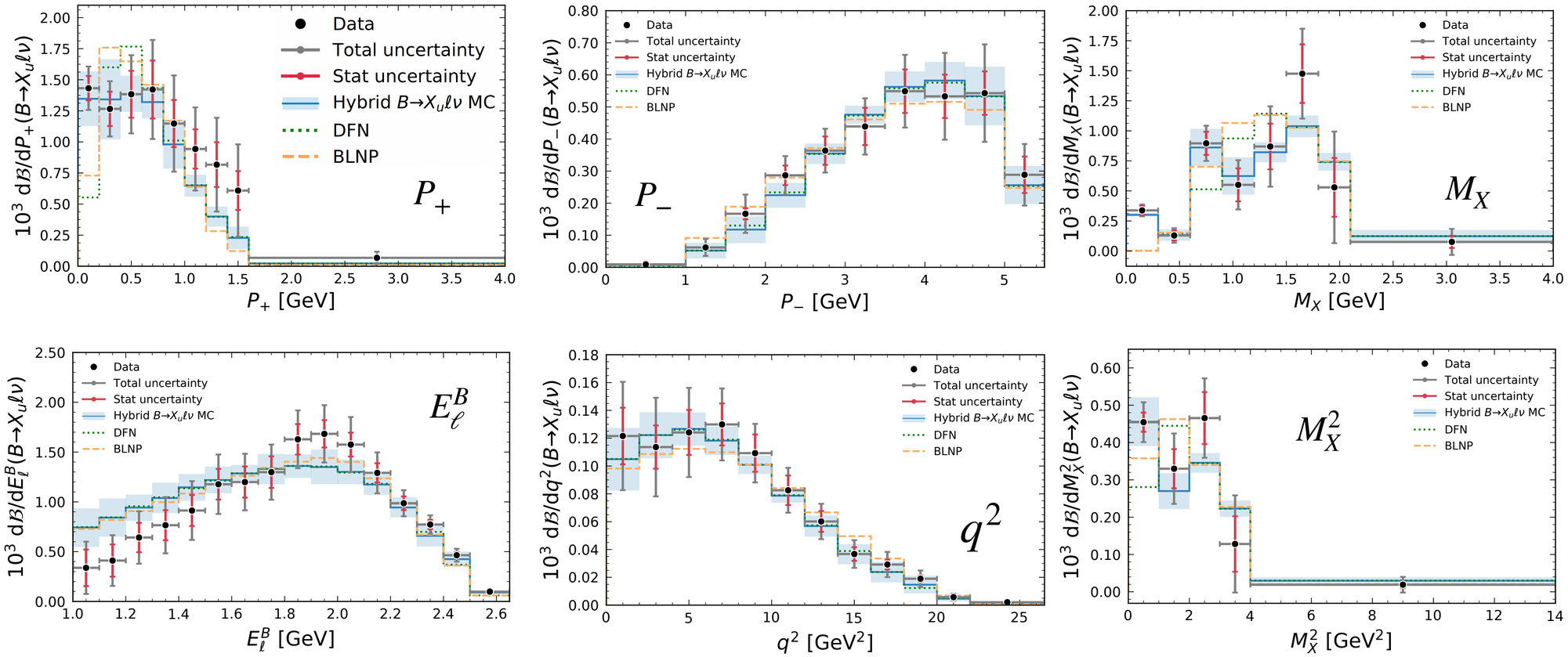
$(4.10 \pm 0.09_{stat} \pm 0.22_{sys} \pm 0.15_{theo}) \times 10^{-3}$

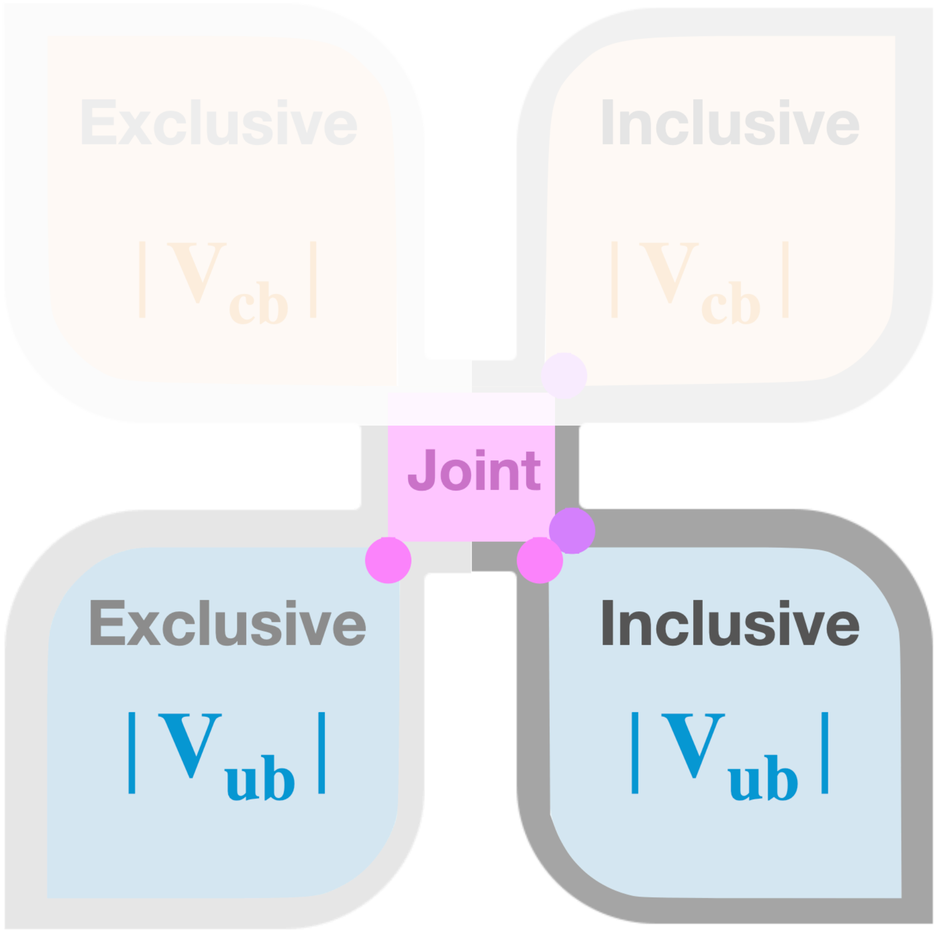
compatible with excl. and CKM expectation within 1.3σ and 1.6σ , respectively

First Measurement of Differential Spectra of $B \to X_u \ell \nu$

PRL 127, 261801 (2021)

- Inherit **same analysis strategy** in the partial BF measurement [PRD 104 , 012008 (2021)]
- Background subtracted via M_X fit, further corrected for efficiency & acceptance effects (phase space: $E_\ell^B > 1$ GeV)
- Necessary input for future **model-independent** determinations of **$|V_{ub}|$** (e.g. NNVub, SIMBA)




Exclusive
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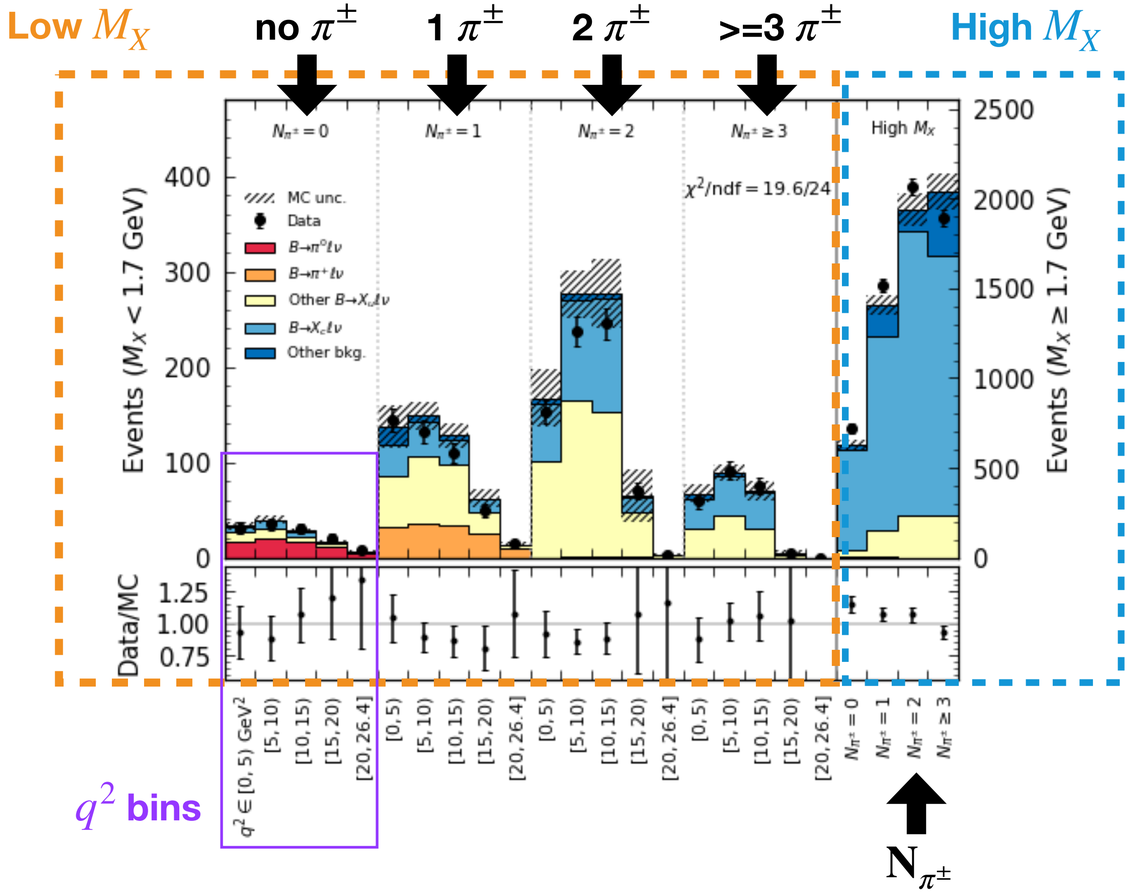
First Simultaneous Determination of Incl. & Excl. $|V_{ub}|$

New

arXiv: 2303.17309

Preliminary

- Inherit **same analysis strategy** in the partial BF measurement [PRD 104 , 012008 (2021)]
- Extract signal in $\mathbf{q^2 : N_{\pi^\pm}}$ for $B \to \pi \ell \nu$ and $B \to X_u \ell \nu$ simultaneously
- Fitter corporates experimental observation of templates' **normalisations** and $B \to \pi \ell \nu$ **form factor (q² shape)**



Fit results provide all $\mathcal{B}$ and $B \to \pi \ell \nu$ FF (decay rate)

=> derive exclusive and inclusive $|V_{ub}|$

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

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

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

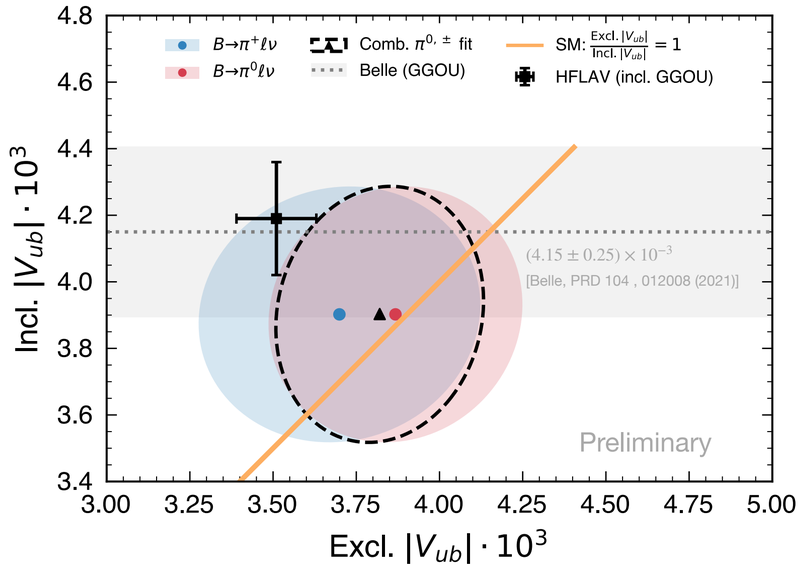
Theoretical decay rate based on GGOU prediction [Gambino-Giordano-Ossola-Uraltsev, JHEP 10 (2007) 058]

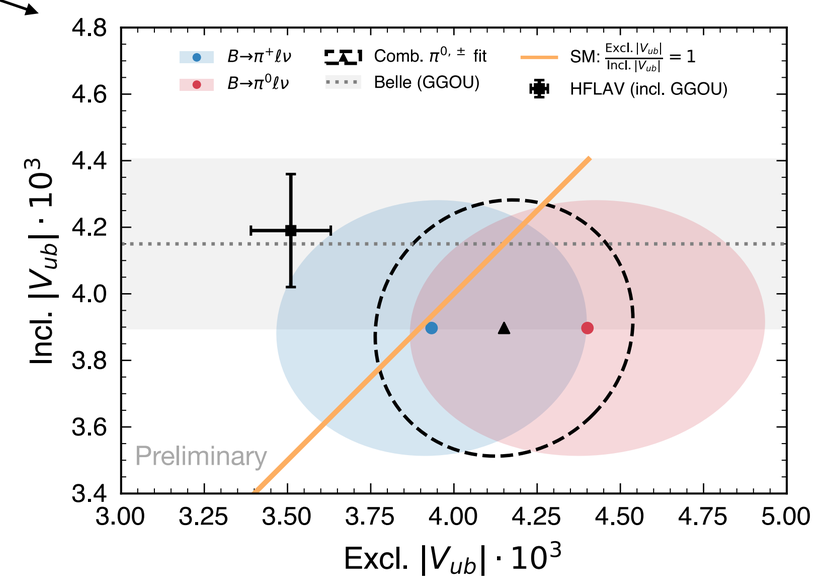
First Simultaneous Determination of Incl. & Excl. $|V_{ub}|$

arXiv: 2303.17309

Preliminary

- Various fit scenarios applied:
  - **Combined** or separate $B \to \pi^+ \ell \nu$, $B \to \pi^0 \ell \nu$ (iso-spin relation)
  - Input BCL constraint: **LQCD + exp.** or **only LQCD** [FLAG: Eur. Phys. J. C 82, 869 (2022)]





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

Preliminary

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

Incl. $(3.90 \pm 0.20_{\text{stat}} \pm 0.32_{\text{syst}} \pm 0.09_{\text{theo}}) \times 10^{-3}$

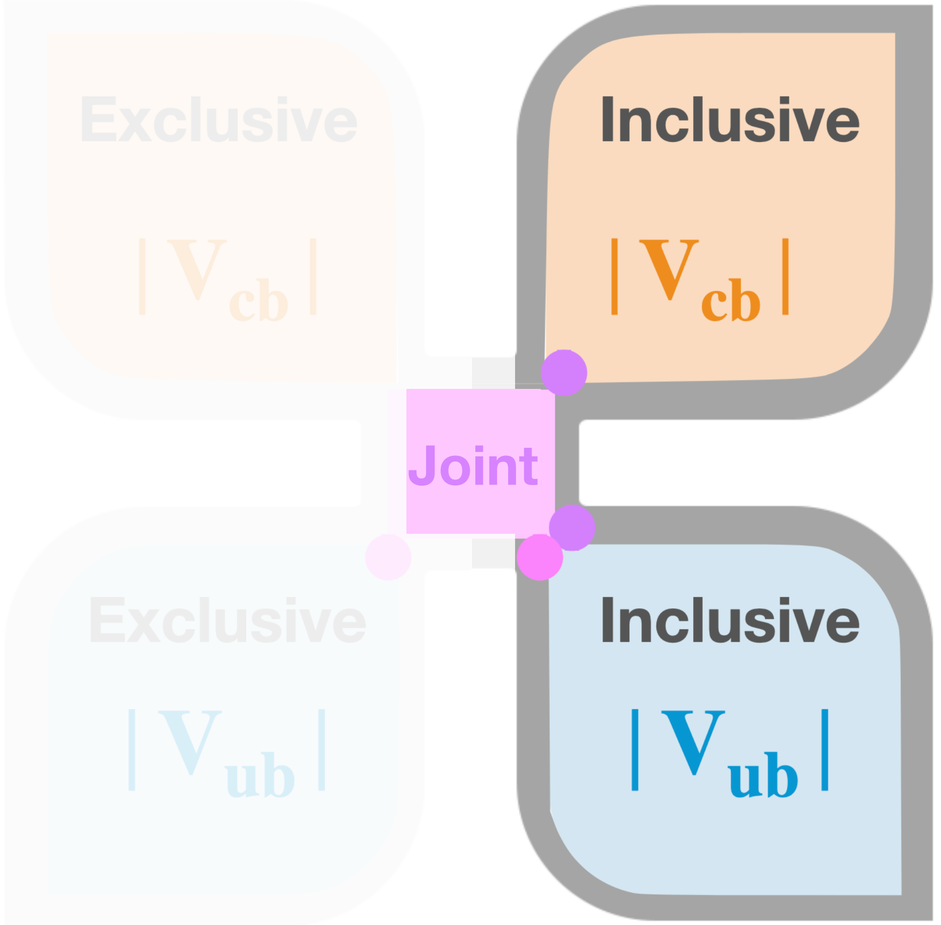
Ratio $0.97 \pm 0.12 \quad (\rho = 0.10)$

Weighted average of excl. & incl.

$(3.85 \pm 0.26) \times 10^{-3}$

CKM global fit (w/o $|V_{ub}|$)**:** $(3.64 \pm 0.07) \times 10^{-3}$**,**

compatible within 0.8σ


Exclusive
$|V_{cb}|$
Inclusive
$|V_{cb}|$
Joint
Exclusive
$|V_{ub}|$
Inclusive
$|V_{ub}|$

Ratio of Inclusive $\Delta\mathcal{B}(B \to X_u \ell \nu)$ and $\Delta\mathcal{B}(B \to X_c \ell \nu)$

Preliminary

- Full Belle data set of 711 fb^{-1} with **Hadronic tagging** using Belle II tool (Full Event Interpretation)
- **Modified** $B \to X_c \ell \nu$ **modeling** using sideband data
- $B \to X_u \ell \nu$ yields extracted in $q^2 : p_\ell^B$
- Measured partial phase space region of $p_\ell^B > 1\,\mathrm{GeV}$ with fractions of $\epsilon_\Delta^u = 86\,\%\,, \epsilon_\Delta^c = 79\,\%$

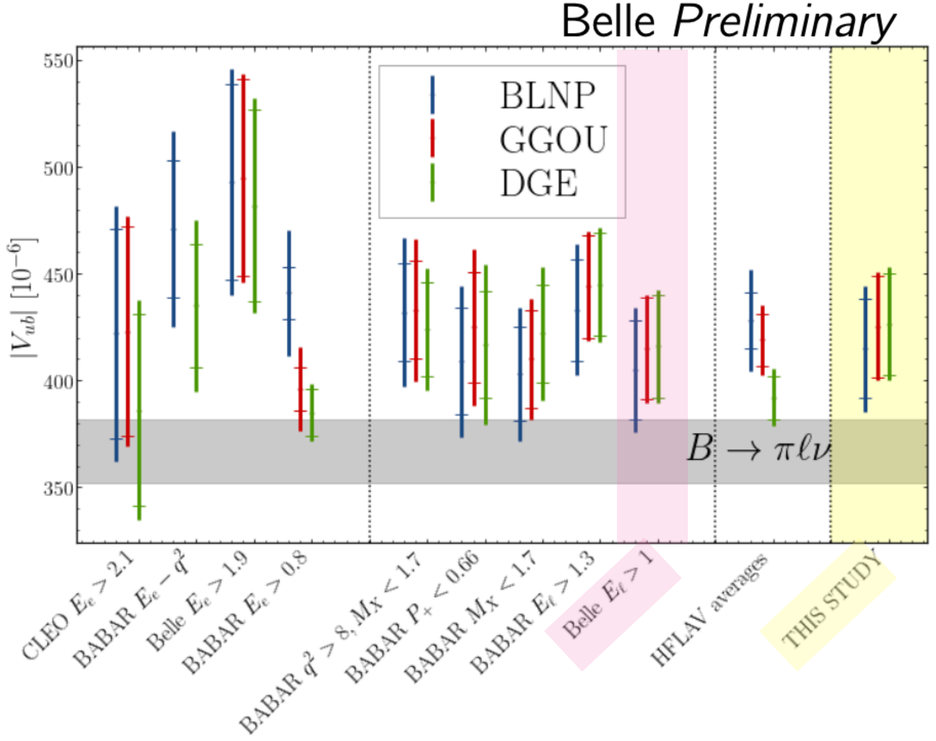
Preliminary

$$\frac{\Delta\mathcal{B}(B \to X_u \ell \nu)}{\Delta\mathcal{B}(B \to X_c \ell \nu)} = 1.95(1 \pm 8.4\%_{\mathrm{stat}} \pm 7.8\%_{\mathrm{syst}}) \times 10^{-2}$$

Based on this, one could try the following two quick and naive conversions

$$|V_{ub}| = \sqrt{\frac{1}{\tau_B \Delta\Gamma(B \to X_u \ell \nu)} \frac{\Delta\mathcal{B}(B \to X_u \ell \nu)}{\Delta\mathcal{B}(B \to X_c \ell \nu)} \Delta\mathcal{B}(B \to X_c \ell \nu)}$$

WA: (8.55 ± 0.13)%



Consistent with recent Belle result PRD 104 , 012008 (2021)

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$$\frac{|V_{ub}|}{|V_{cb}|} = \sqrt{\frac{\Delta\mathcal{B}(B \to X_u \ell \nu)}{\Delta\mathcal{B}(B \to X_c \ell \nu)} \frac{\Delta\Gamma(B \to X_c \ell \nu)}{\Delta\Gamma(B \to X_u \ell \nu)}}$$

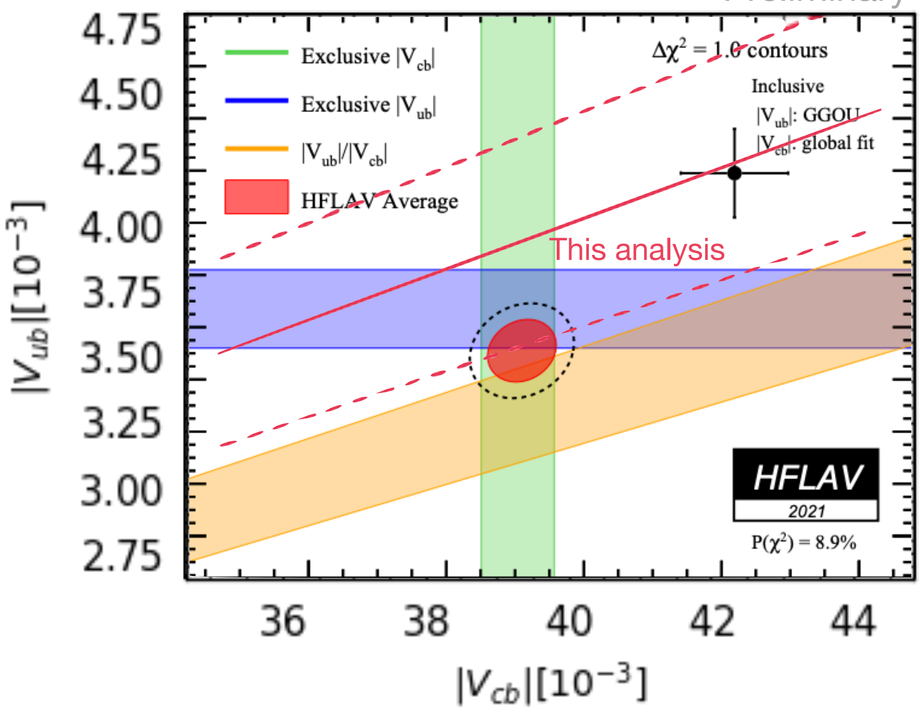
Theo. decay rates:

[PRD 107, 052008 (2023)]

$$\Delta\Gamma^{\mathrm{GGOU}}(B \to X_u \ell \nu) = 58.5 \pm 2.7\,\mathrm{ps}^{-1}$$

$$\Delta\Gamma^{\mathrm{Kin}}(B \to X_c \ell \nu) = 29.9 \pm 1.2\,\mathrm{ps}^{-1}$$

Preliminary



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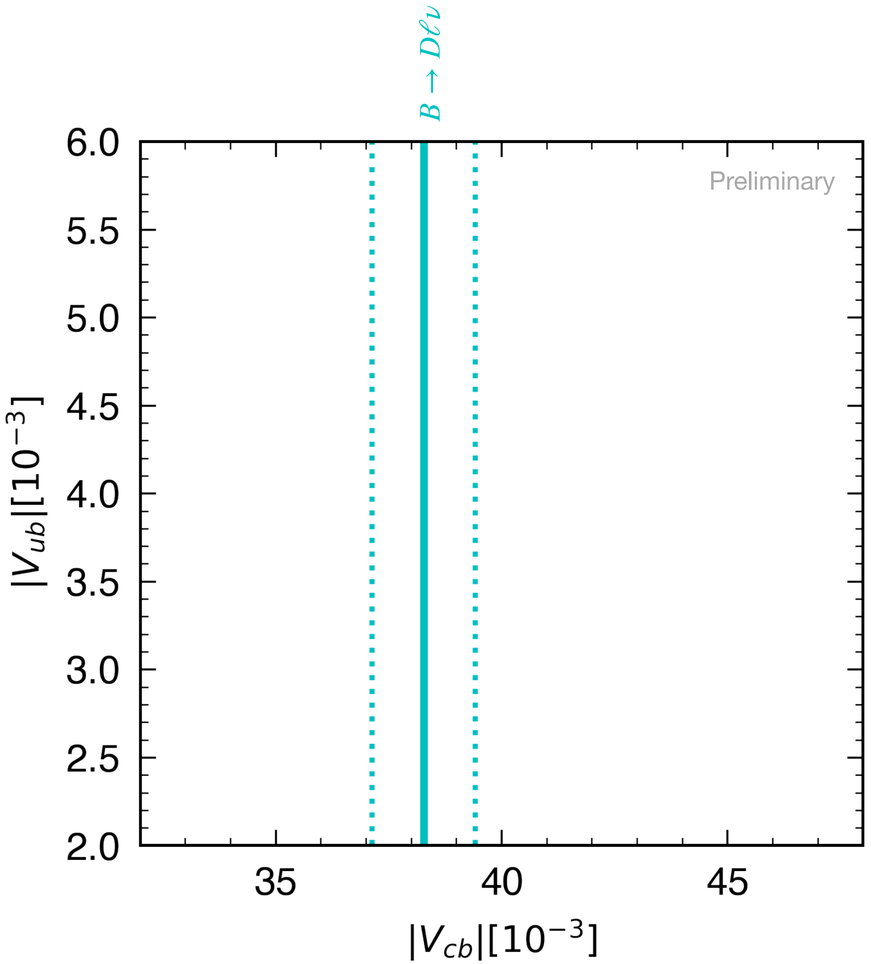

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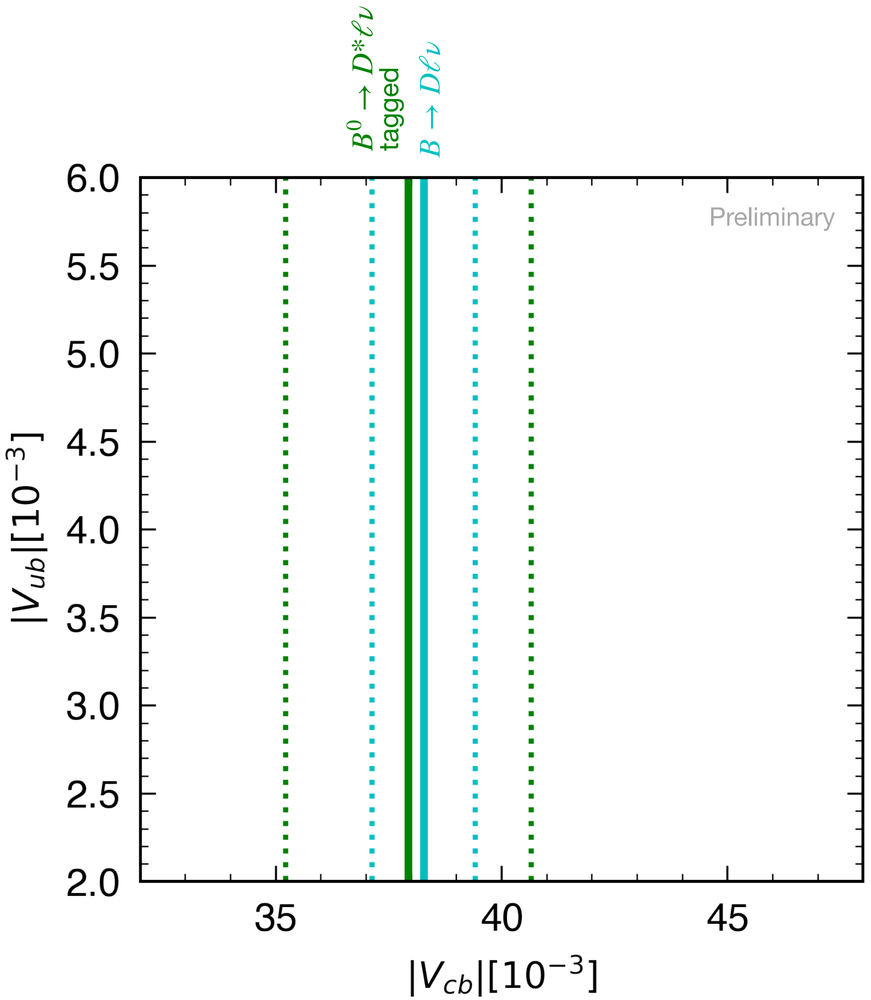

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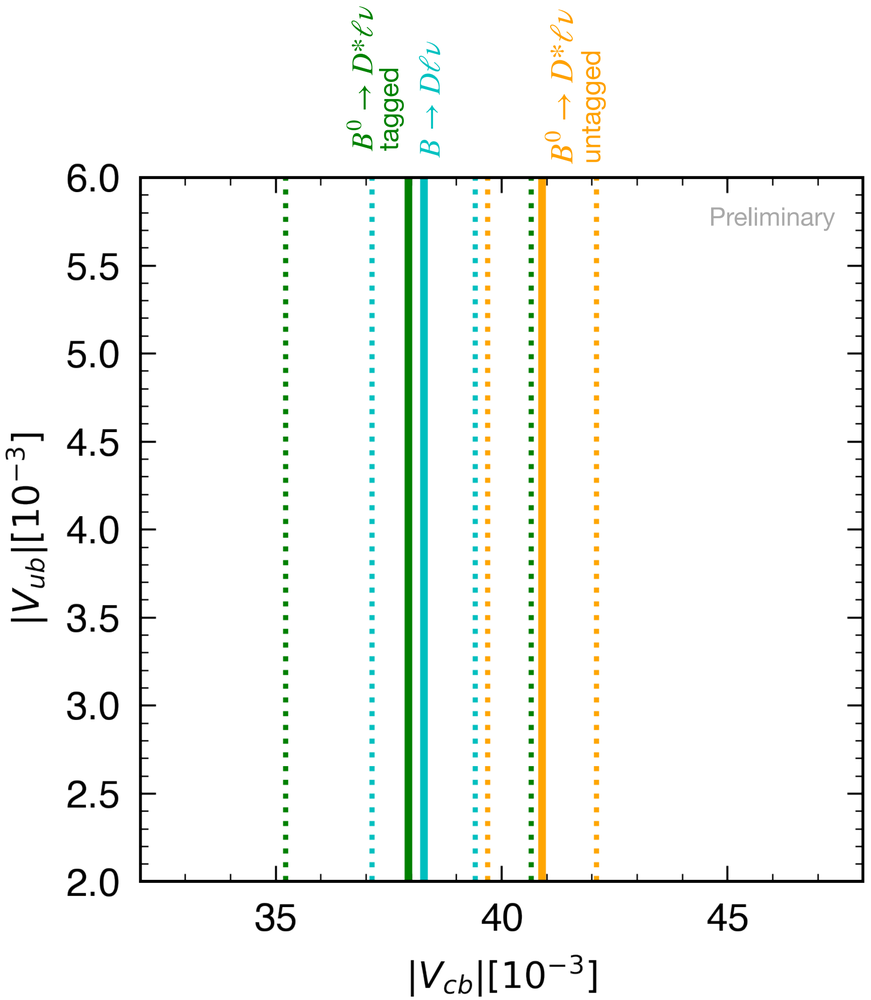

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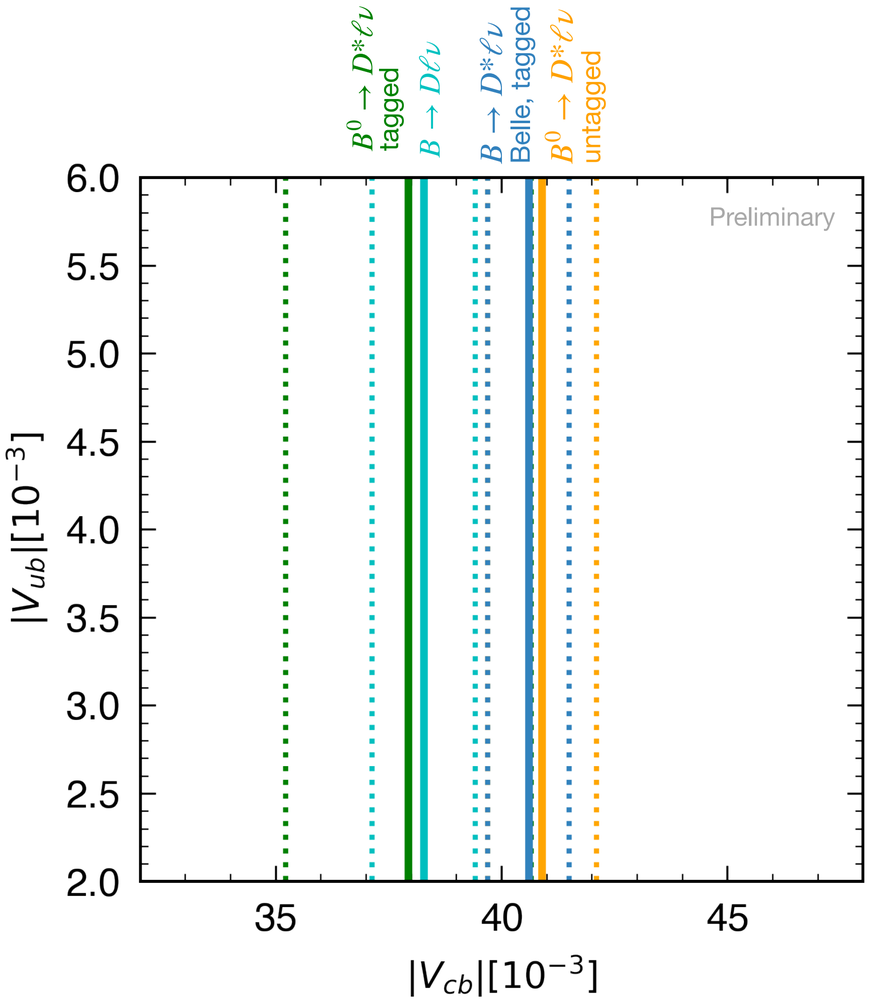

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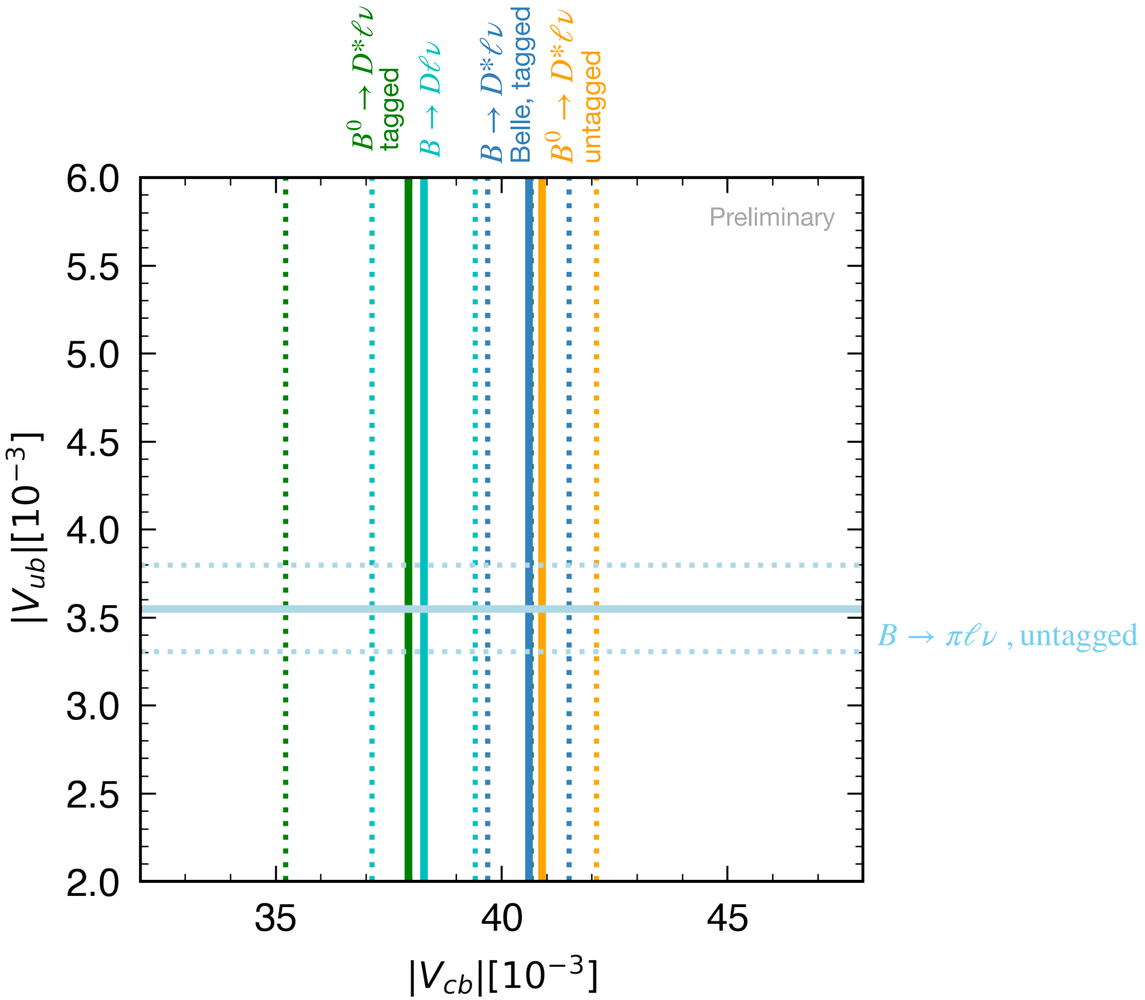

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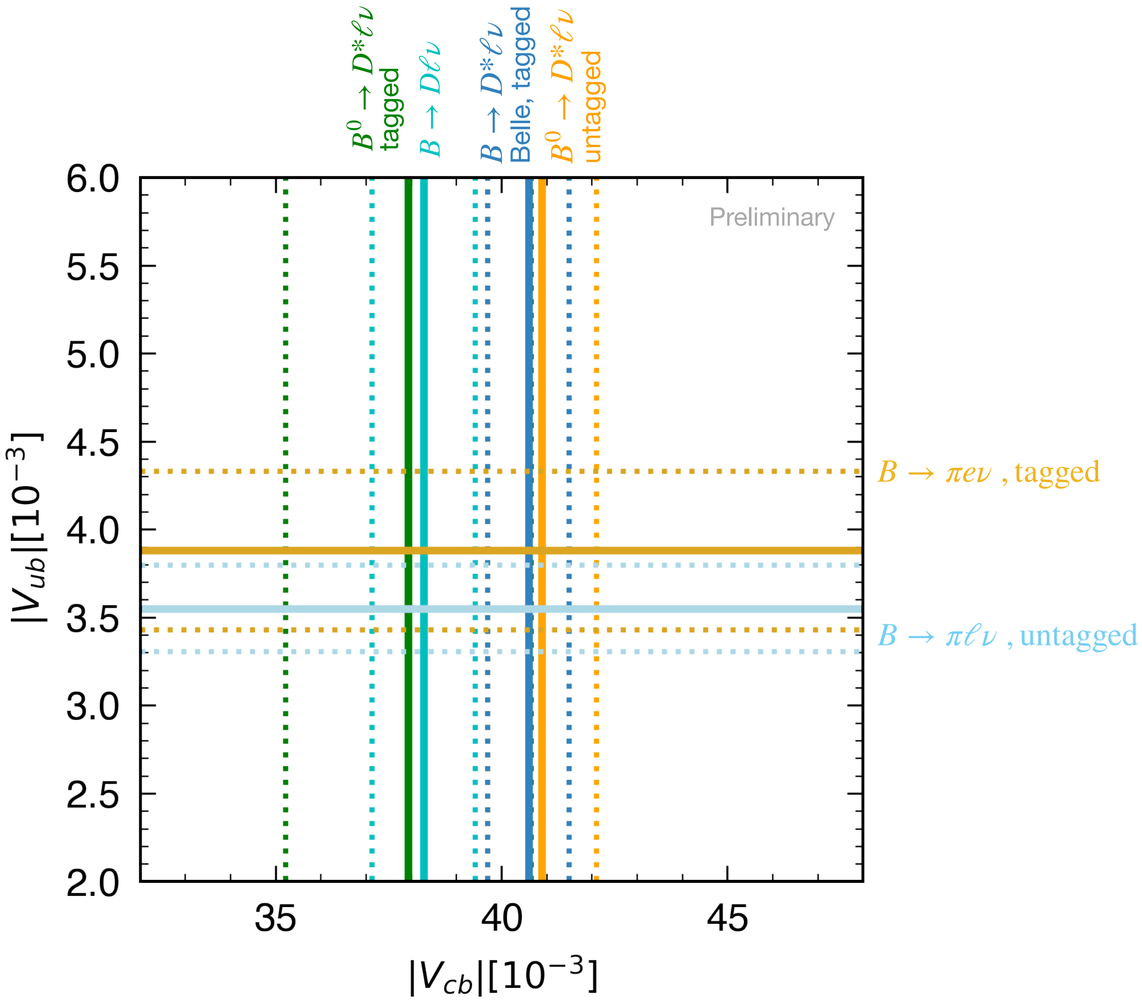

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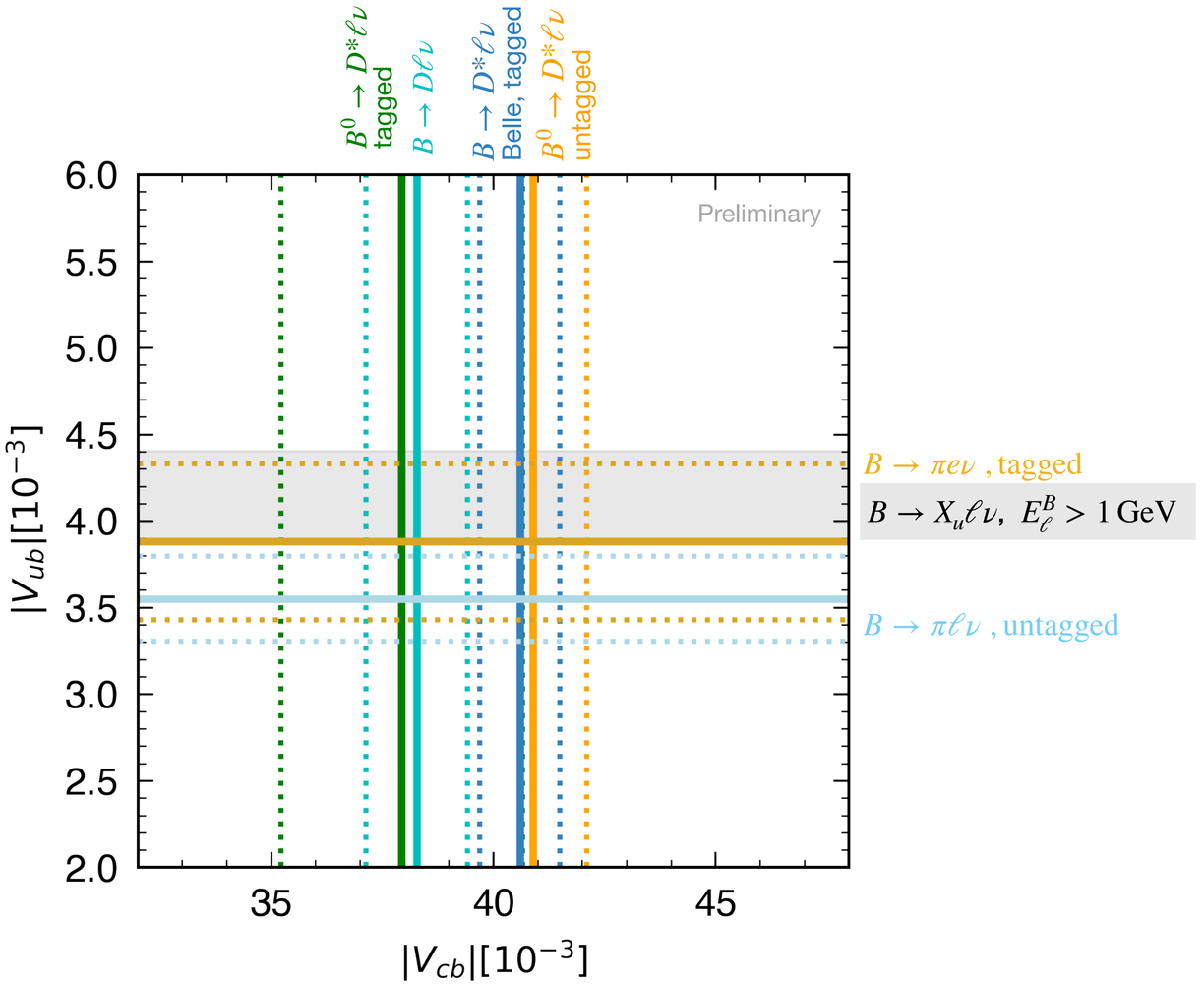

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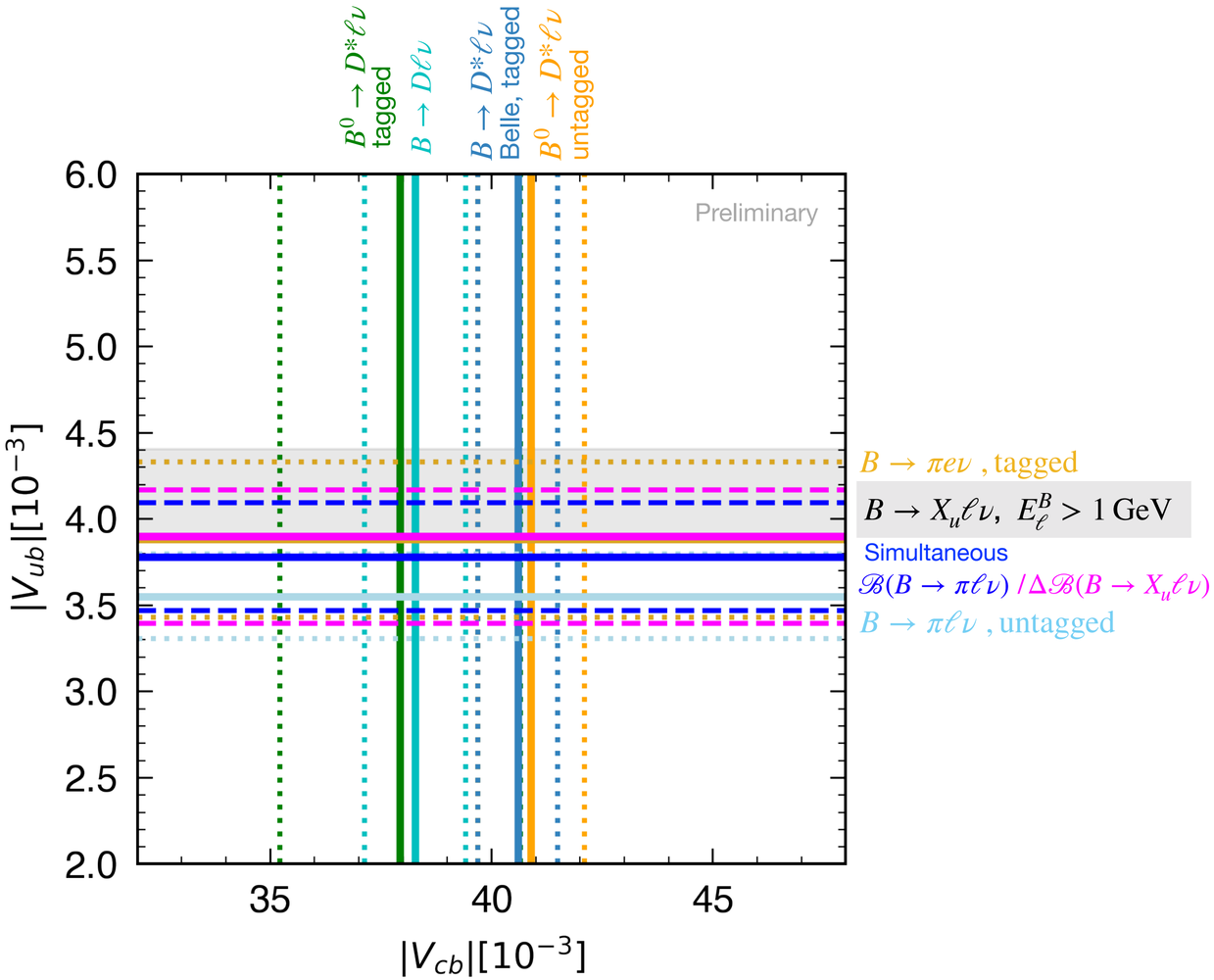

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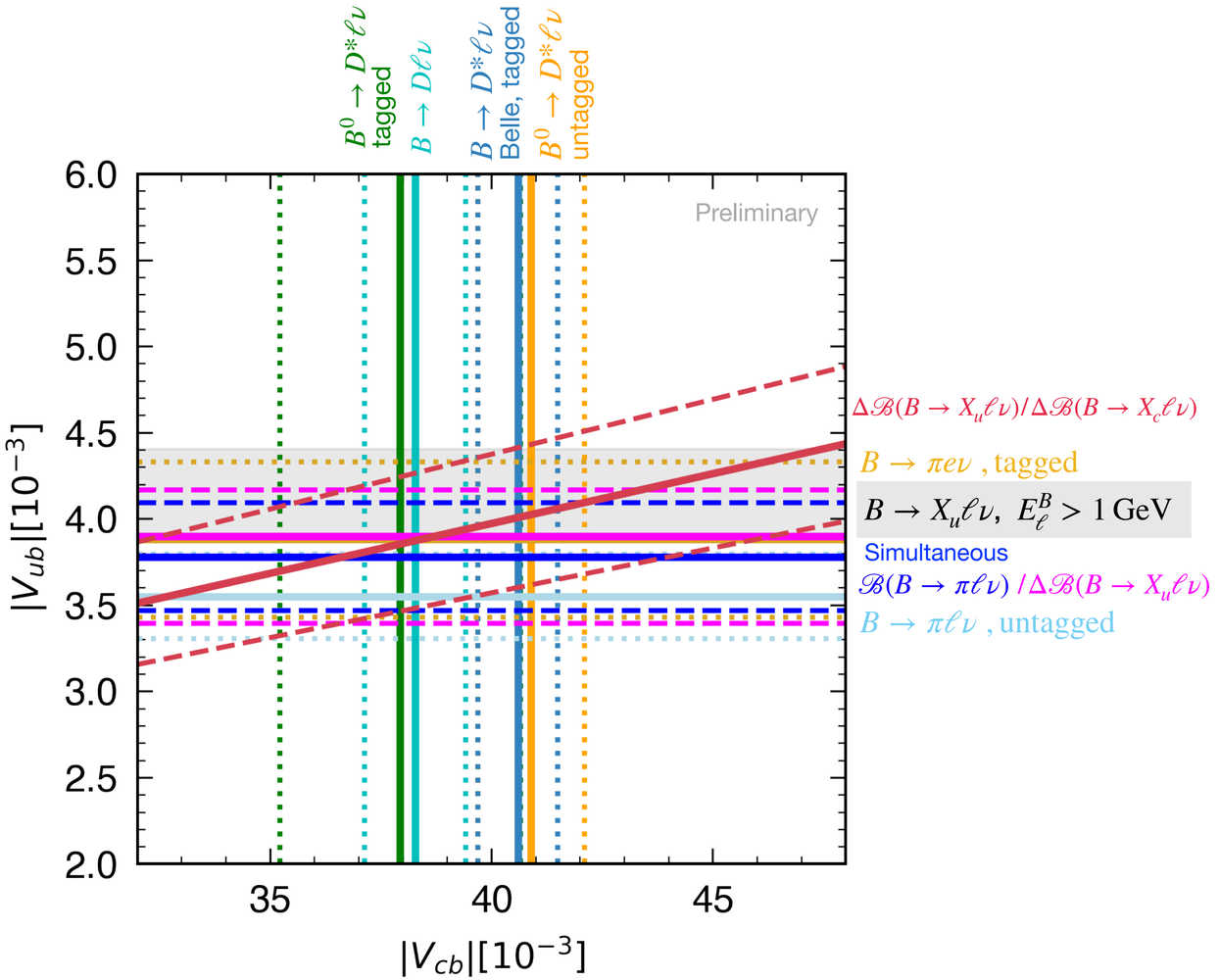

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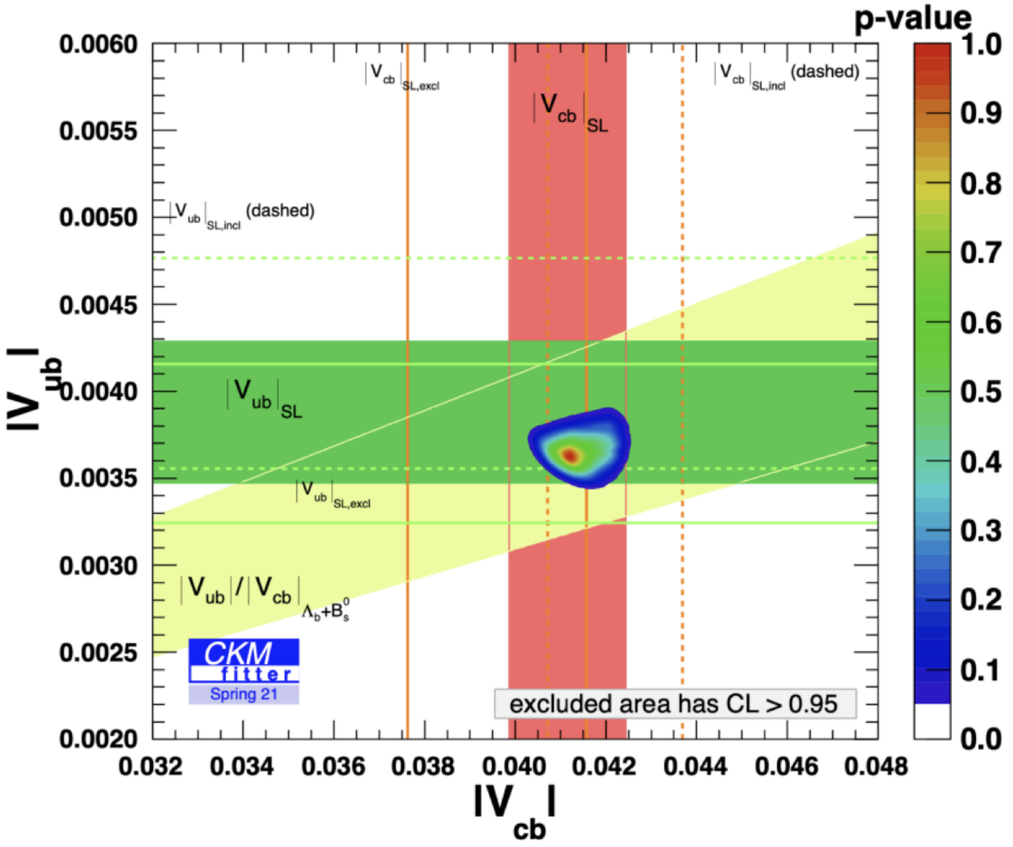

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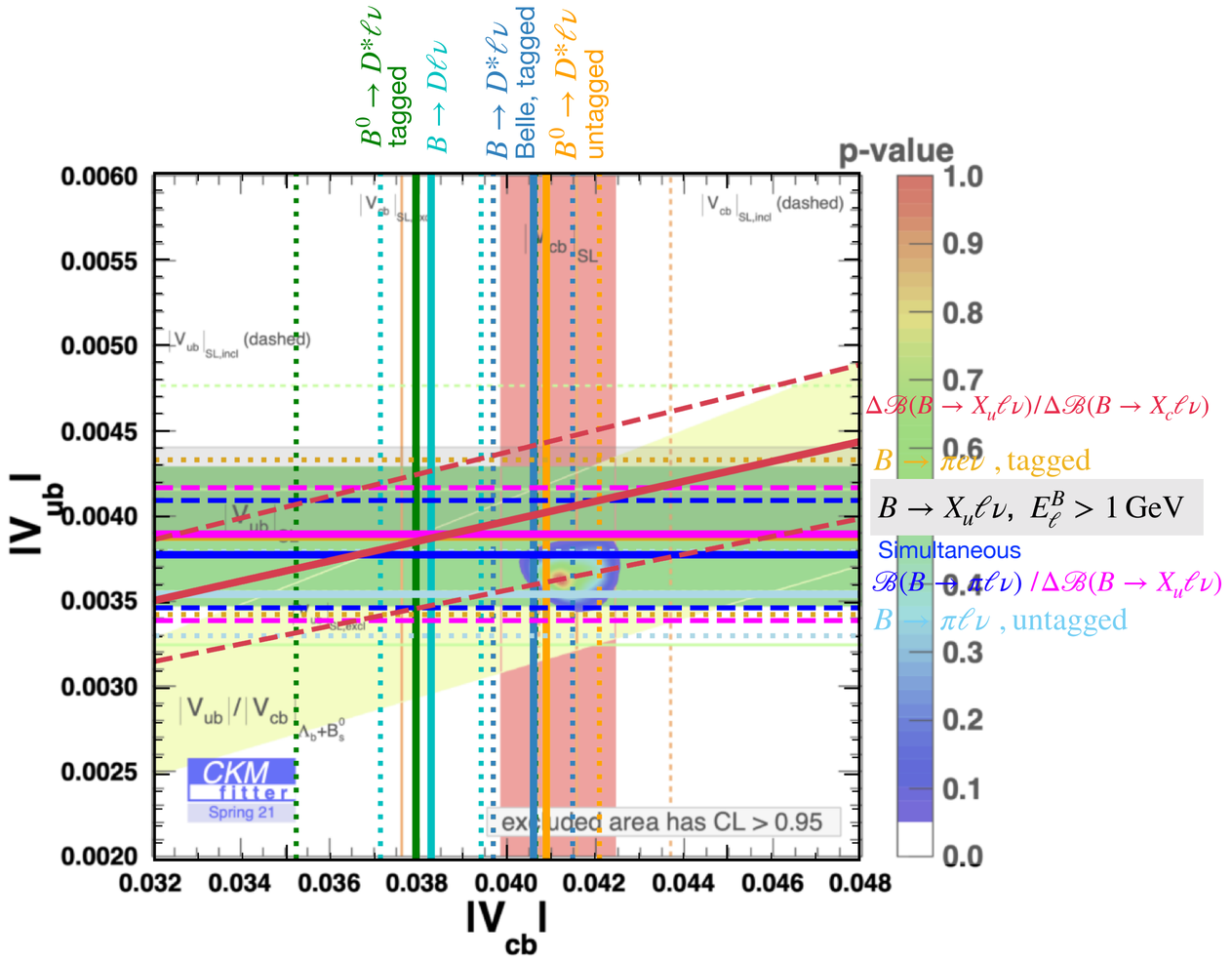
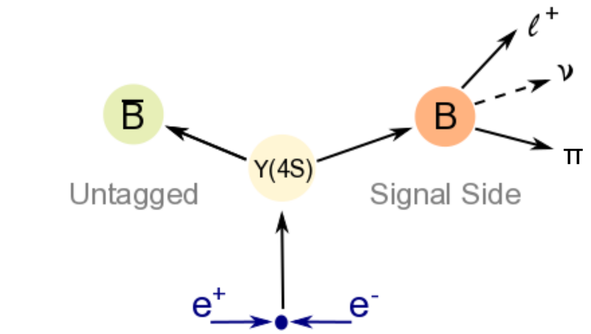


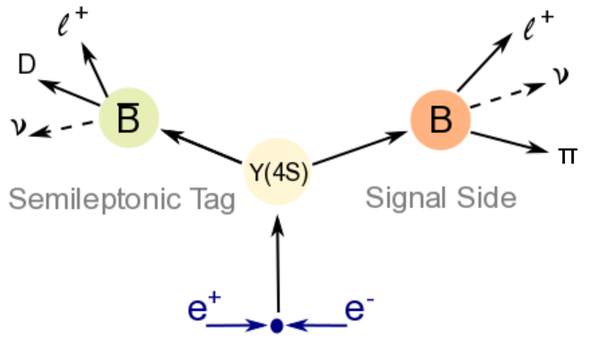
THANK YOU

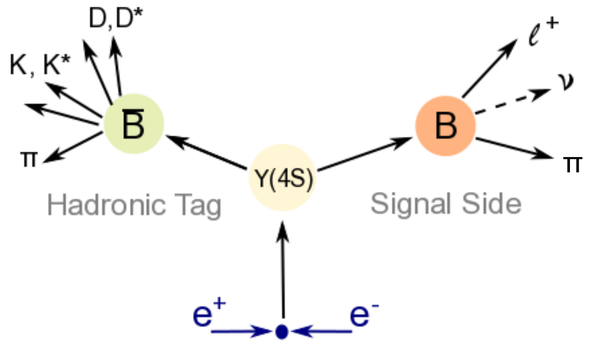
Backup: Tagging vs. Untagging

purity

efficiency







- Untagged
  - Loose constraints on signal
  - Very large statistics, but also very large background
  - Efficiency $\epsilon \approx \mathcal{O}(100\%)$
- Semileptonic tag
  - Mid-range reconstruction efficiency
  - Due to multiple neutrinos, less information about B_{tag}
- Hadronic tag
  - Cleaner sample
  - Knowledge of $p(B_{sig})$
  - Low tag-side efficiency $\epsilon \approx \mathcal{O}(0.1\%)$

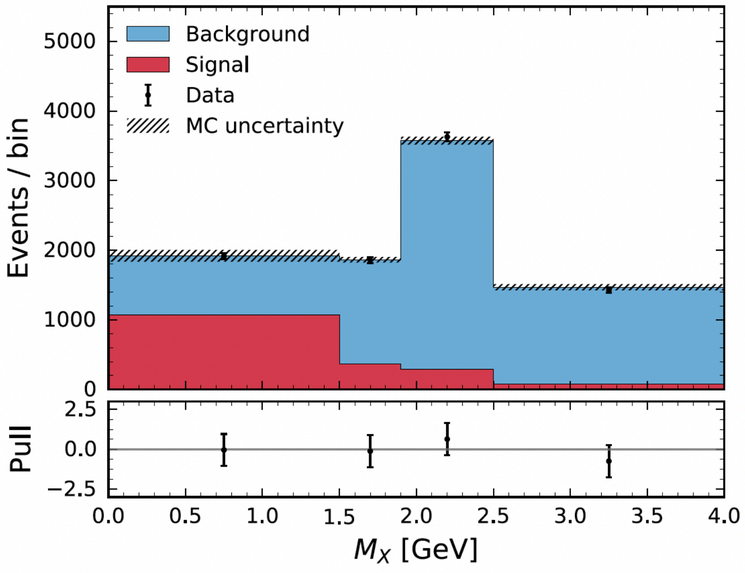
Backup: Inclusive $B \to X_u \ell \nu$ and $|V_{ub}|$

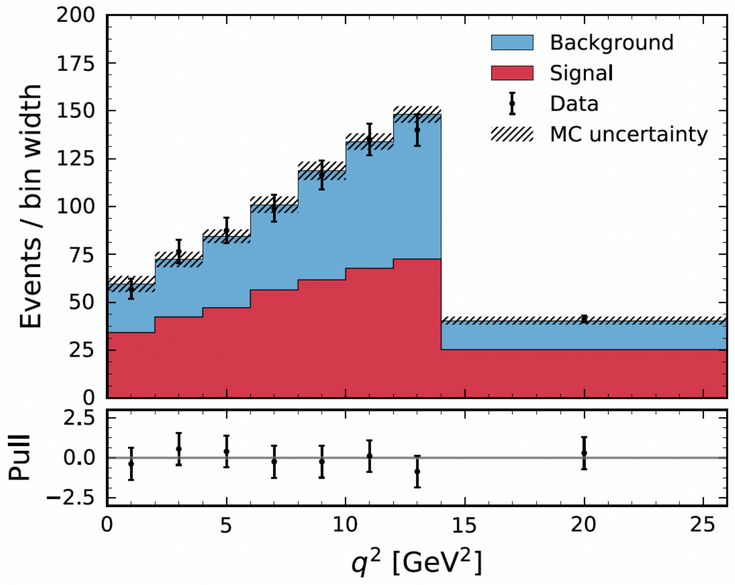
PRD 104 , 012008 (2021)

- Extract signal using binned likelihood in **3 phase space (PS) regions:**
  - $E_\ell^B > 1$ GeV (covers 86% of available signal PS)
  - $E_\ell^B > 1$ GeV, $M_X < 1.7$ GeV (56%)
  - $E_\ell^B > 1$ GeV, $M_X < 1.7$ GeV, $q^2 > 8$ GeV^2 (31%)

→ Fit either E_ℓ^B , M_X , q^2 or 2D (M_X : q^2)

Projection of 2D fit result





$$\Delta\mathcal{B}(B \to X_u \ell^+ \nu_\ell; \mathrm{Reg}) = \frac{\hat{\eta}_{\mathrm{sig}} \cdot \epsilon_{\Delta\mathcal{B}(\mathrm{Reg})}}{4(\epsilon_{\mathrm{tag}} \cdot \epsilon_{\mathrm{sel}}) \cdot N_{BB}}$$

$$\Delta\mathcal{B}(E_\ell^B > 1\mathrm{GeV}) = (1.59 \pm 0.07 \pm 0.16) \times 10^{-3}$$

Measurements separate for B^+, B^0, e, μ modes

Backup: New Method of Extracting $|V_{ub}^{\text{incl.}}|$

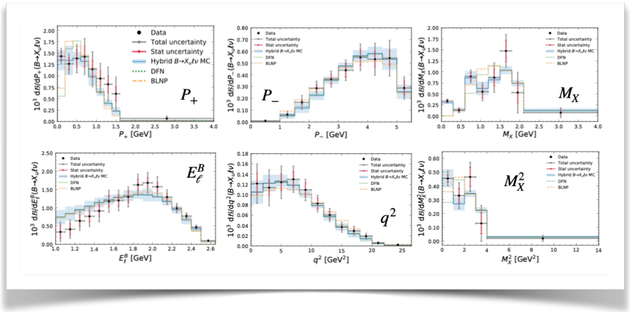
- Allows direct extraction of coefficients for non-perturbative shape functions in a global fit and $|V_{ub}|$
- Uncertainty can be further shrinked by including other inclusive B decays, e.g $B\to X_s\gamma$, $B\to X_c\ell\nu$ as the shape function in LO is universal
- Methods proposed by SIMBA, NNVub

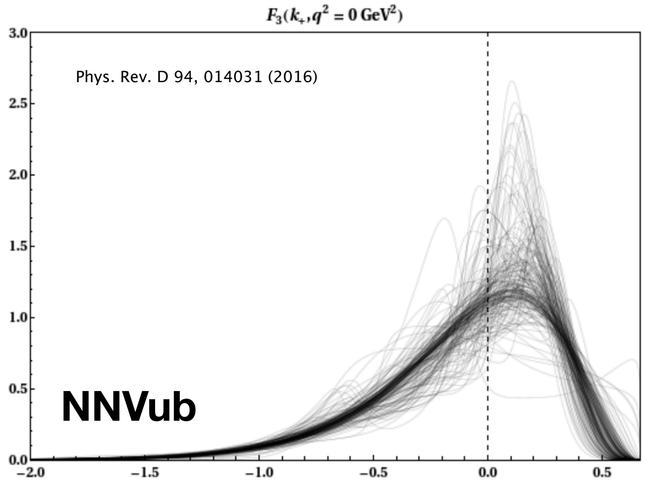
What can we gain for incl. $|V_{ub}|$?

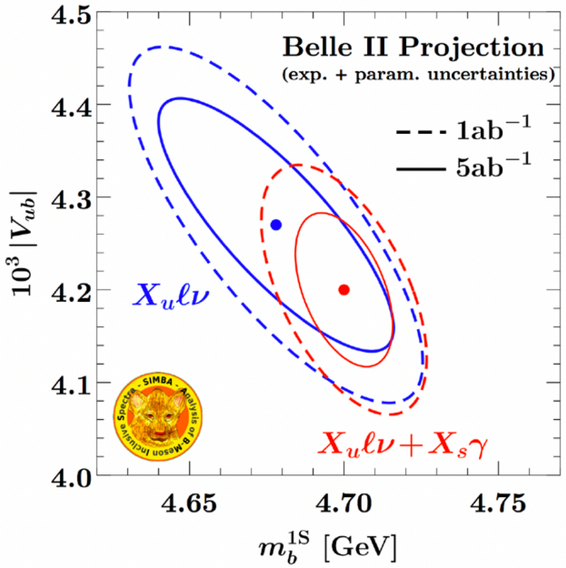
Direct & more model-independent extraction

Normalization ⇒ Kin. shapes + Normalization

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(B\to X_u\ell\nu)}{\tau_B\cdot\Delta\Gamma(B\to X_u\ell\nu)}}$$







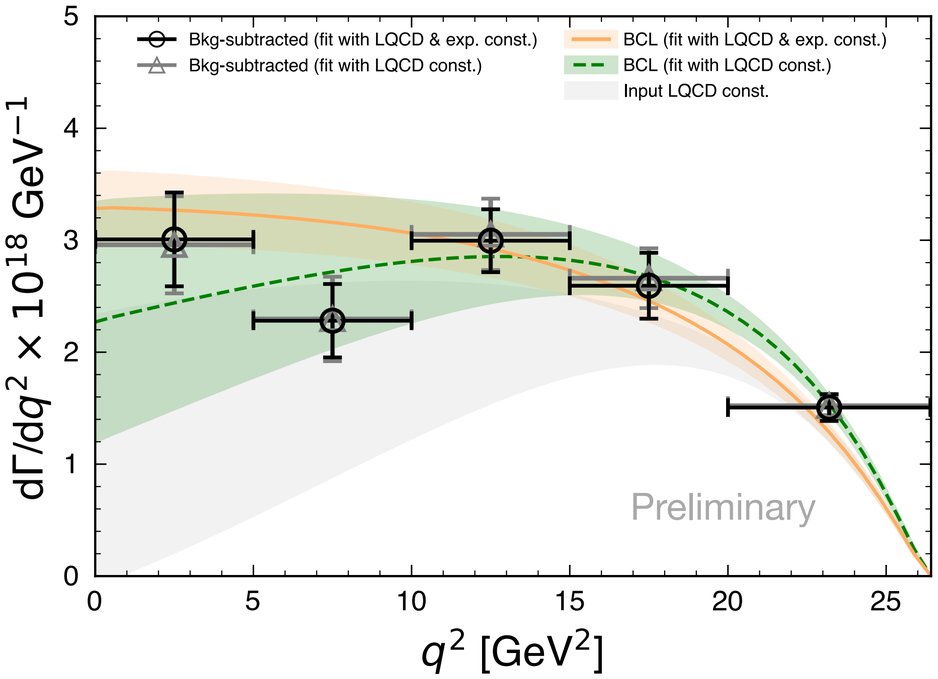
Tightly collaborating with both theory groups to extract $|V_{ub}^{\text{incl.}}|$ (work in progress)

Backup: Simultaneous Determination of Incl. & Excl. $|V_{ub}|$

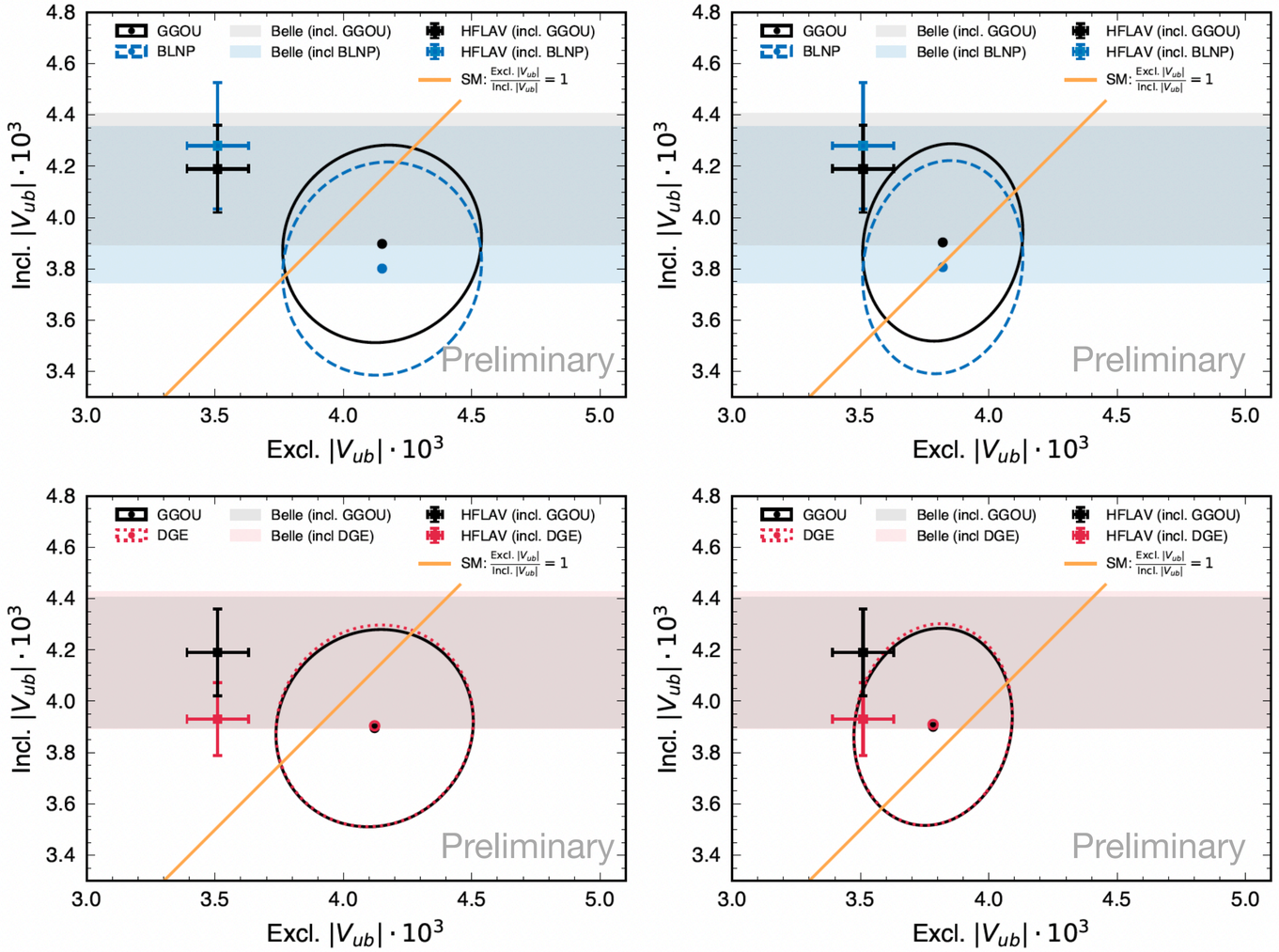
arXiv: 2303.17309

Preliminary

Decay rate as a function of q^2 with fitted BCL para.

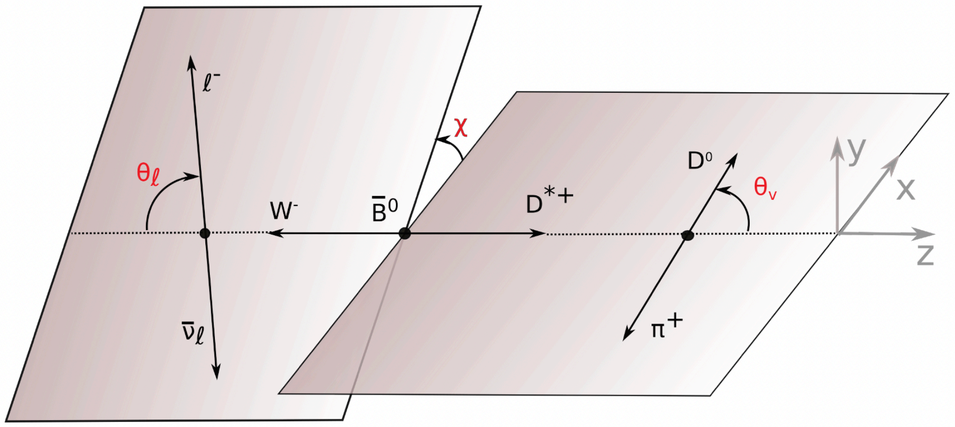


Results with various input of inclusive decay rates

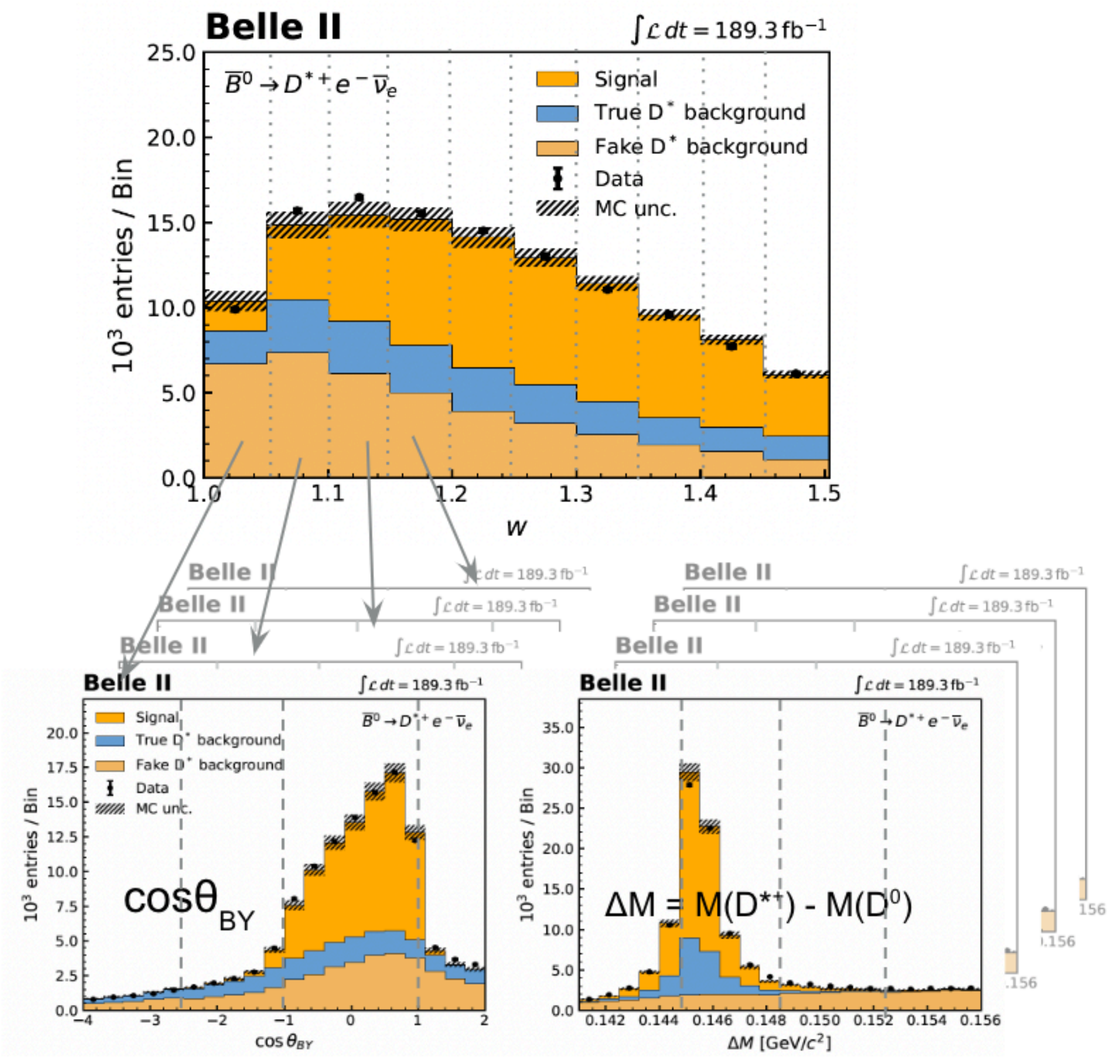


Backup: Branching Fraction of $B^0 \to D^* \ell \nu$ and $|V_{cb}|$

- Select events with energetic lepton $p^{CM} > 1.2$ GeV, and $\Delta M = M(D^{*+}) - M(D^0) = [0.141, 0.156]$ GeV, $\cos\theta_{BY} = [-4, 2]$
- 2D binned linkelihood fit on ($\cos\theta_{BY}$, $\Delta M = M(D^{*+}) - M(D^0)$) for each bin of kinematic variables: **w**, **$\cos\theta_\ell$**, **$\cos\theta_v$**, χ
- Systematic shape variations incorporated as bin-wise Nuisance para. for each fit template



$$\cos\theta_{BY} = \frac{2E_B^{\mathrm{CM}} E_Y^{\mathrm{CM}} - m_B^2 - m_Y^2}{2|\vec{p}_B^{\,\mathrm{CM}}||\vec{p}_Y^{\,\mathrm{CM}}|}$$



integral projection

Backup: Branching Fraction of $B^0 \to D^* \ell \nu$ and $|V_{cb}|$

Preliminary

- Nested hypothesis test included with LQCD beyond-recoil constraints

BGL$_{132}$

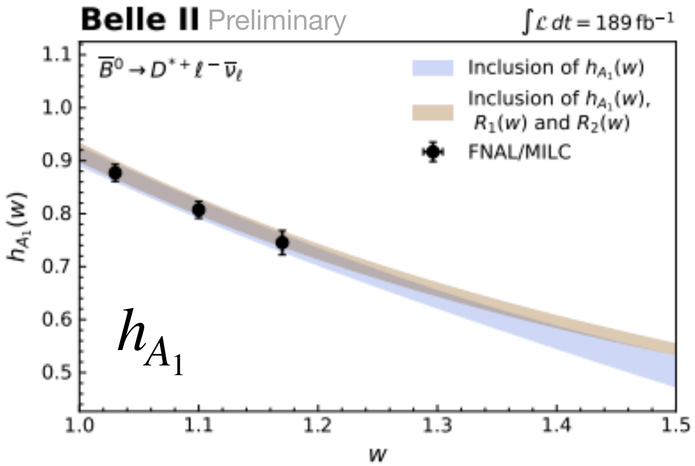
Preliminary

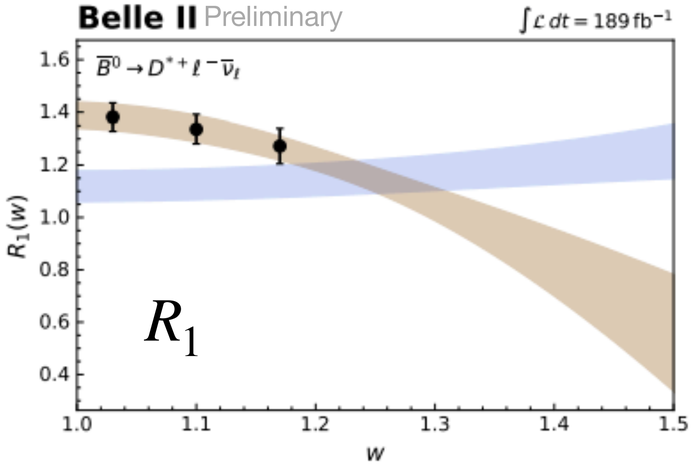
	Values	Correlations					
$\lvert V_{cb}\rvert \times 10^3$	40.2 ± 1.2	1	−0.32	−0.58	−0.11	0.03	−0.24
$a_0 \times 10^3$	22.6 ± 1.2	−0.32	1	0.31	0.1	−0.18	0.31
$b_0 \times 10^3$	13.2 ± 0.2	−0.58	0.31	1	−0.17	0.14	−0.12
$b_1 \times 10^3$	7.1 ± 14.1	−0.11	0.1	−0.17	1	−0.89	0.57
b_2	-0.4 ± 0.4	0.03	−0.18	0.14	−0.89	1	−0.41
$c_1 \times 10^3$	-0.7 ± 0.8	−0.24	0.31	−0.12	0.57	−0.41	1

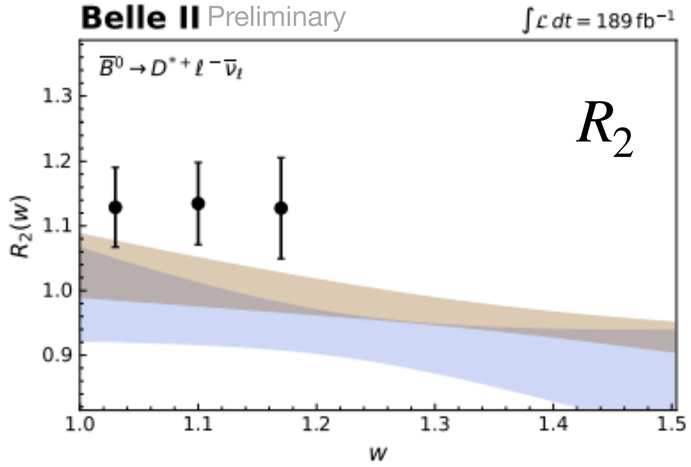
BGL$_{313}$

Preliminary

	Values	Correlations						
$\lvert V_{cb}\rvert \times 10^3$	39.8 ± 1.1	1	−0.16	0.02	−0.1	−0.61	−0.16	0.11
$a_0 \times 10^3$	28.3 ± 1.0	−0.16	1	−0.09	−0.2	0.17	0.11	−0.03
$a_1 \times 10^3$	-45.9 ± 65.7	0.02	−0.09	1	−0.85	−0.04	−0.09	0.14
a_2	-4.8 ± 2.4	−0.1	−0.2	−0.85	1	0.12	0.13	−0.17
$b_0 \times 10^3$	13.3 ± 0.2	−0.61	0.17	−0.04	0.12	1	0.11	−0.13
$c_1 \times 10^3$	-3.2 ± 1.4	−0.16	0.11	−0.09	0.13	0.11	1	−0.91
$c_2 \times 10^3$	59.1 ± 29.9	0.11	−0.03	0.14	−0.17	−0.13	−0.91	1







Backup: $|V_{cb}|$ & Differential Shapes of $B \to D^* \ell \nu$

- Signal **shapes** corrected for resolution, reco. efficiency and acceptance effects
- Combined **all kinematic shapes** to extract $|V_{cb}|$ in **BGL/CLN** with external constraints on **branching fractions** (HFLAV) and **LQCD results** (FNAL/MILC)

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

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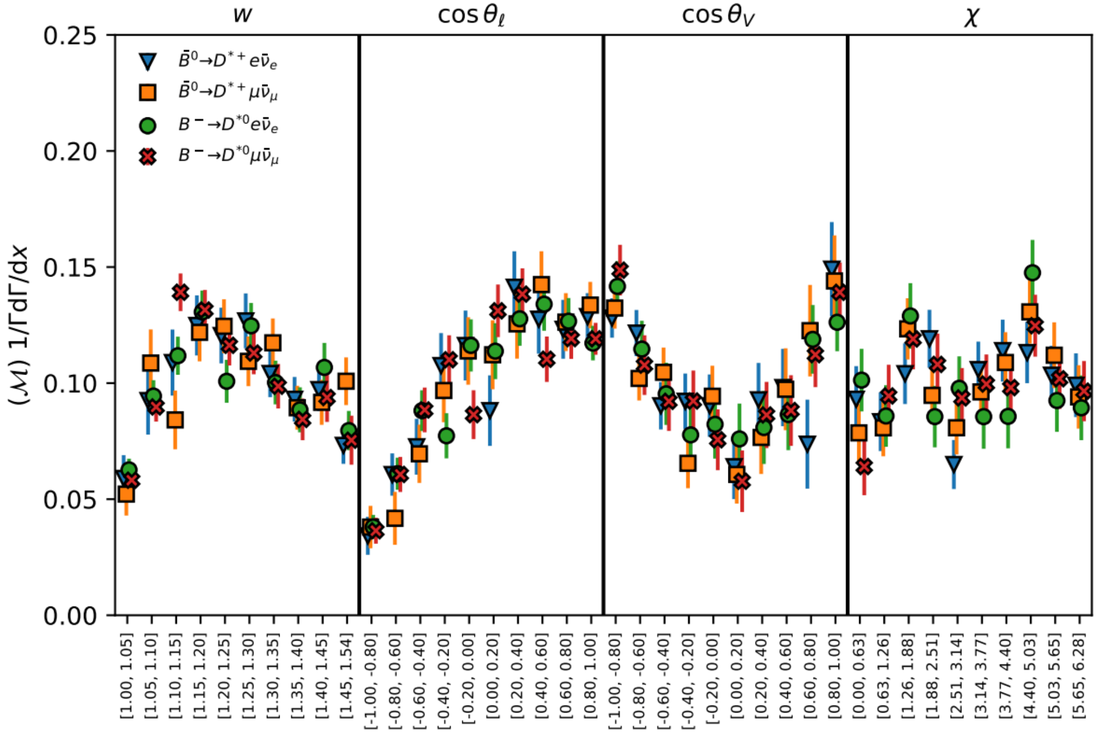
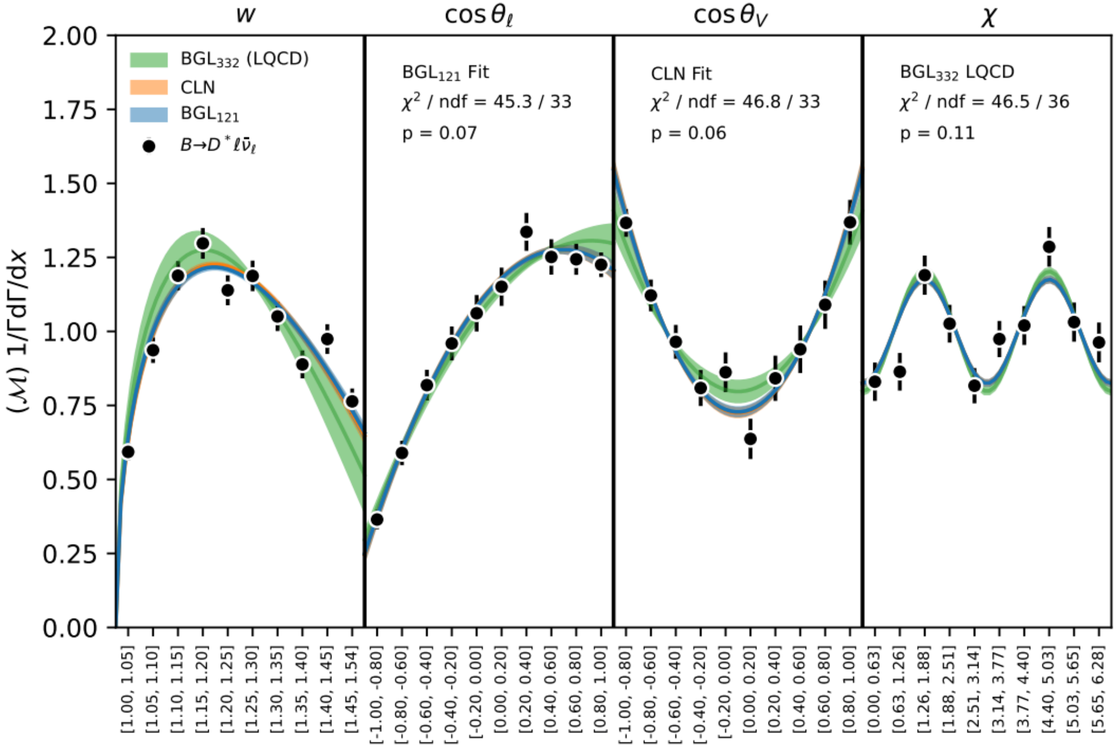
Corrected Shapes



Fitted Shapes



Backup: $|V_{cb}|$ & Differential Shapes of $B \to D^* \ell \nu$

arXiv: 2301.07529

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- Nested hypothesis test w/o & w/ LQCD beyond-recoil constraints