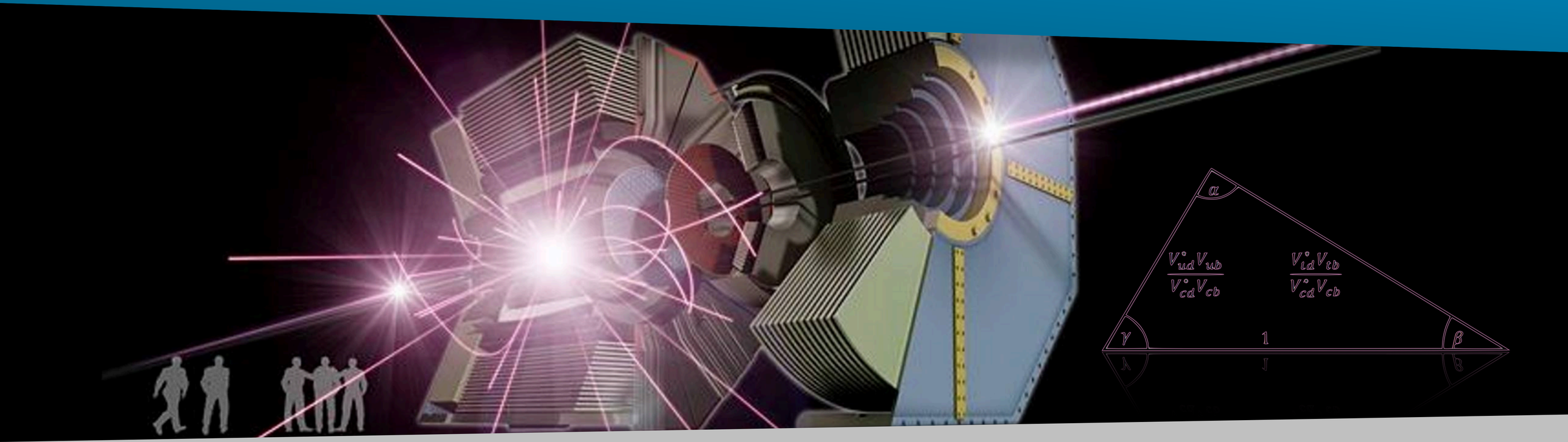
Status of $|V_{xb}|$ measurements from Belle (II)



曹　璐

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全国第二十届重味物理和CP破坏研讨会　2023年12月16日

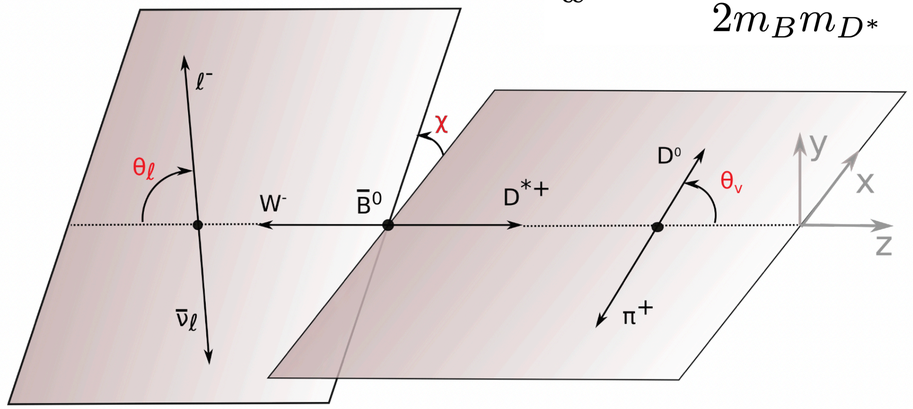
$|V_{cb}|$

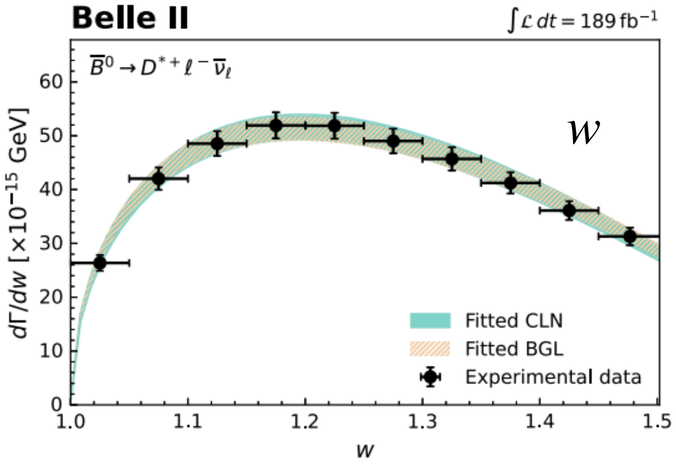
Measurement of $B^0 \to D^* \ell \nu$ Decays at Belle II

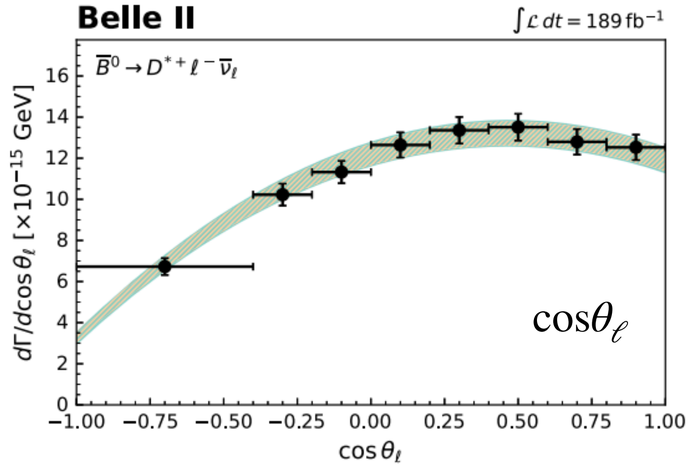
PRD 108, 092013 (2023)

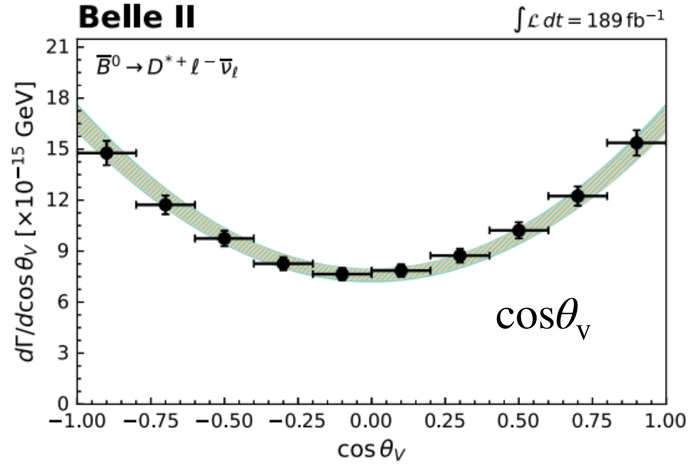
- Decay chain: **$B^0 \to D^{*+} \ell\nu$, $D^{*+} \to D^0\pi^+_{slow}$, $D^0 \to K^- \pi^+$**
- Untagged strategy (higher efficiency than tagged)
- Select energetic signal lepton $p^{CM} > 1.2$ GeV
- Measured total $\mathcal{B}$ and differential spectra: recoil parameter **w**, and angles **$\cos\theta_\ell$**, **$\cos\theta_v$**, χ
- **Extract $|V_{cb}|$, lepton angular asymmetry, D* longitudinal polarization fractions**

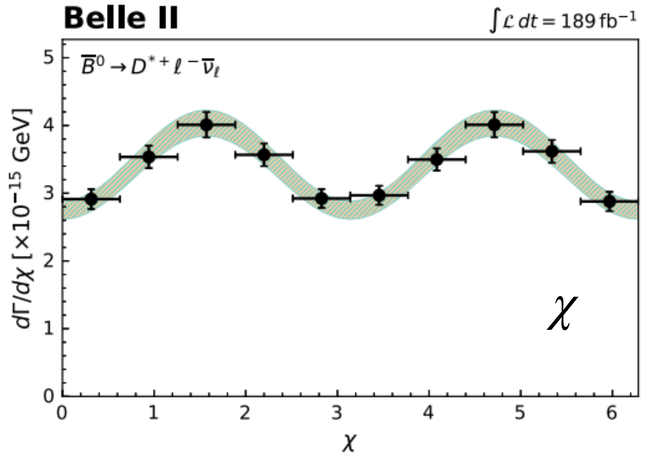
$$w = \frac{m_B^2 + m_{D^*}^2 - q^2}{2 m_B m_{D^*}}$$











Measurement of $B^0 \to D^* \ell \nu$ Decays at Belle II

- 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]

Traditional way

$$\chi^2 = \sum_{i,j}^{34} \left(\frac{\Delta\Gamma_i^{\text{obs}}}{\Gamma^{\text{obs}}} - \frac{\Delta\Gamma_i^{\text{pre}}}{\Gamma^{\text{pre}}} \right) C_{ij}^{-1} \left(\frac{\Delta\Gamma_j^{\text{obs}}}{\Gamma^{\text{obs}}} - \frac{\Delta\Gamma_j^{\text{pre}}}{\Gamma^{\text{pre}}} \right) \quad \text{<= shape}$$

$$+ \frac{(\Gamma^{\text{obs}} - \Gamma^{\text{pre}})^2}{\sigma_\Gamma^2}, \quad \text{<= normalization}$$

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

$$|V_{cb}|_{\text{BGL}} = (40.57 \pm 0.31 \pm 0.95 \pm 0.58) \times 10^{-3}$$

$$|V_{cb}|_{\text{CLN}} = (40.13 \pm 0.27 \pm 0.93 \pm 0.58) \times 10^{-3}$$

stat. — syst. (dominated by slow pion tracking eff. leptonID) — LQCD uncertainty on F(1)

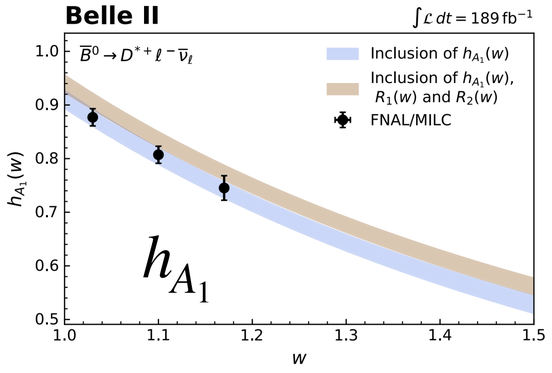
Measurement of $B^0 \to D^* \ell \nu$ Decays at Belle II

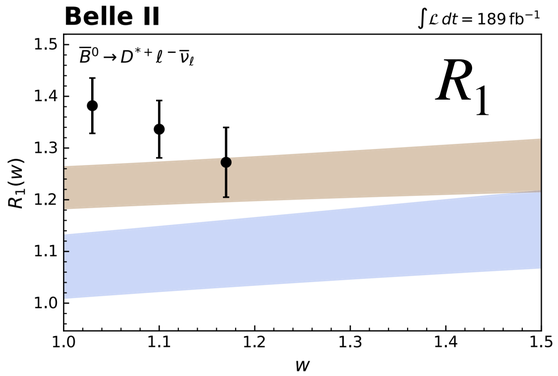
- Fit differential shapes on w, cosθ_ℓ, cosθ_v, χ with **Caprini-Lellouch-Neubert (CLN)** [Nucl. Phys. B530, 153] & **Boyd-Grinstein-Lebed (BGL) parameterisations** [Phys. Rev. D56, 6895)]
- BGL truncation based on nested hypothesis test [Phys. Rev. D100, 013005]
- Inclusion of **LQCD constraints** [MILC: EPJC 82, 1141 (2022)] **at beyond zero-recoil** (w = [1.03, 1.10, 1.17]) in two scenarios

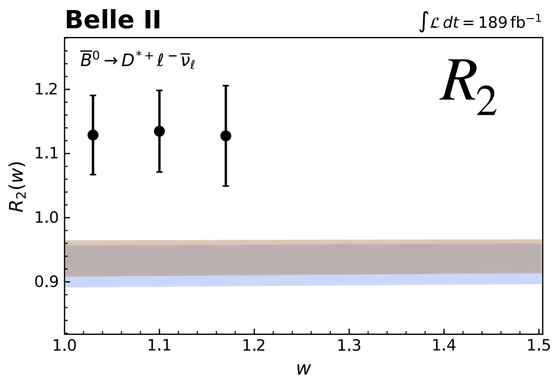
$$\chi^2 = \sum_{i,j}^{34} \left(\frac{\Delta\Gamma_i^{\rm obs}}{\Gamma^{\rm obs}} - \frac{\Delta\Gamma_i^{\rm pre}}{\Gamma^{\rm pre}} \right) C_{ij}^{-1} \left(\frac{\Delta\Gamma_j^{\rm obs}}{\Gamma^{\rm obs}} - \frac{\Delta\Gamma_j^{\rm pre}}{\Gamma^{\rm pre}} \right) + \frac{(\Gamma^{\rm obs} - \Gamma^{\rm pre})^2}{\sigma_\Gamma^2} + \sum_{ij} (F_i^{\rm LQCD} - F_i^{\rm exp}) C_{ij}^{-1} (F_j^{\rm LQCD} - F_j^{\rm exp})$$

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 ± 1.3	25.6 ± 0.8
$b_0 \times 10^3$	13.19 ± 0.24	13.61 ± 0.23
$b_1 \times 10^3$	-6 ± 6	2 ± 6
$c_1 \times 10^3$	-0.9 ± 0.7	-0.0 ± 0.7
$\lvert V_{cb} \rvert \times 10^3$	40.3 ± 1.2	38.3 ± 1.1
χ^2/ndf	39/33	75/39
p value	21%	0.04%

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







Similar tension seen in recent Belle (2023) measurement [PRD 108, 012002 (2023)]

⇒ Both found large disagreements wrt LQCD results on R_2

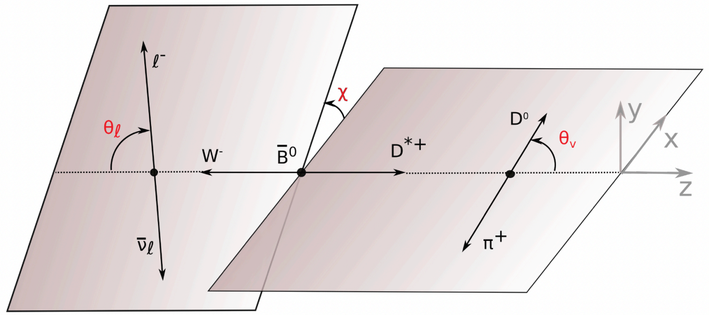
Measurement of $B^0 \to D^* \ell \nu$ Decays at Belle II

PRD 108, 092013 (2023)

- Lepton-flavor-universality tested with separate results on $\mathcal{B}$ of e & mu modes
- All in **good agreement with SM expectations**

$$R_{e/\mu} = 0.998 \pm 0.009 \pm 0.020$$

stat. syst.



Test on forward-backward asymmetry

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

$$\mathcal{A}_{\rm FB}^e = 0.228 \pm 0.012 \pm 0.018,$$

$$\mathcal{A}_{\rm FB}^\mu = 0.211 \pm 0.011 \pm 0.021,$$

$$\Delta\mathcal{A}_{\rm FB} = (-17 \pm 16 \pm 16) \times 10^{-3}$$

Test on D* longitudinal polarization fraction

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

$$F_L^e = 0.520 \pm 0.005 \pm 0.005$$

$$F_L^\mu = 0.527 \pm 0.005 \pm 0.005$$

$$\Delta F_L = 0.006 \pm 0.007 \pm 0.005$$

Angular Coefficients of $B \to D^{*}\ell\nu$

- Full Belle data set of 711 fb^{-1} for $B^{\pm,0}$, $\ell = e, \mu$
- **Hadronic tagging** and background subtracted via fitting M^2_{miss}
- Instead of binning in w, cosθ$_\ell$, cosθ$_v$, χ, measure total **12 angular coefficients J_i in four bins of w** => 4D differential decay rate
  - Angles provide information on, e.g. forward-backward asymmetry, longitudinal polarization fraction
  - "S" observables sensitive to new physics ($J_{7,8,9} = 0$ in SM)
- **Extract |V$_{cb}$| with external constraint on normalisation + LQCD beyond zero-recoil**
- Can also test **LFU** via $\Delta = J_i^e - J_i^\mu$

arXiv: 2310.20286
preliminary

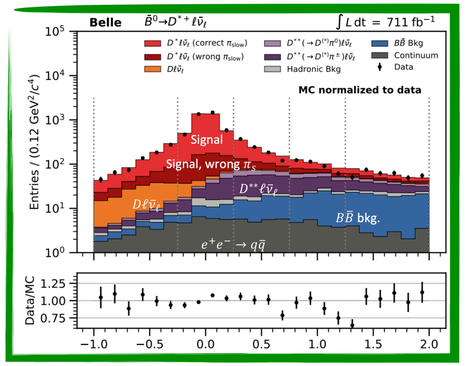
Phys.Rev.D 90 (2014) 9, 094003

$$\bar{J}_i = \frac{1}{N_i} \sum_{j=1}^{8} \sum_{k,l=1}^{4} \eta^{\chi}_{i,j} \eta^{\theta_\ell}_{i,k} \eta^{\theta_V}_{i,l} \left| \chi^{(j)} \otimes \chi^{(k)} \otimes \chi^{(l)} \right|$$

$J_i = J_i(w)$

Normalization Weights Unfolded Yields

J_i	η_i^χ	$\eta_i^{\theta_\ell}$	$\eta_i^{\theta_V}$	normalization N_i
J_{1s}	$\{+\}$	$\{+,a,a,+\}$	$\{-,c,c,-\}$	$2\pi(1)2$
J_{1c}	$\{+\}$	$\{+,a,a,+\}$	$\{+,d,d,+\}$	$2\pi(1)(2/5)$
J_{2s}	$\{+\}$	$\{-,b,b,-\}$	$\{-,c,c,-\}$	$2\pi(-2/3)2$
J_{2c}	$\{+\}$	$\{-,b,b,-\}$	$\{+,d,d,+\}$	$2\pi(-2/3)(2/5)$
J_3	$\{+,-,-,+,+,-,-,+\}$	$\{+\}$	$\{+\}$	$4(4/3)^2$
J_4	$\{+,+,-,-,-,-,+,+\}$	$\{+,+,-,-\}$	$\{+,+,-,-\}$	$4(4/3)^2$
J_5	$\{+,+,-,-,-,-,+,+\}$	$\{+\}$	$\{+,+,-,-\}$	$4(\pi/2)(4/3)$
J_{6s}	$\{+\}$	$\{+,+,-,-\}$	$\{-,c,c,-\}$	$2\pi(1)2$
J_{6c}	$\{+\}$	$\{+,+,-,-\}$	$\{+,d,d,+\}$	$2\pi(1)(2/5)$
J_7	$\{+,+,+,+,-,-,-,-\}$	$\{+\}$	$\{+,+,-,-\}$	$4(\pi/2)(4/3)$
J_8	$\{+,+,+,+,-,-,-,-\}$	$\{+,+,-,-\}$	$\{+,+,-,-\}$	$4(4/3)^2$
J_9	$\{+,+,-,-,+,+,-,-\}$	$\{+\}$	$\{+\}$	$4(4/3)^2$

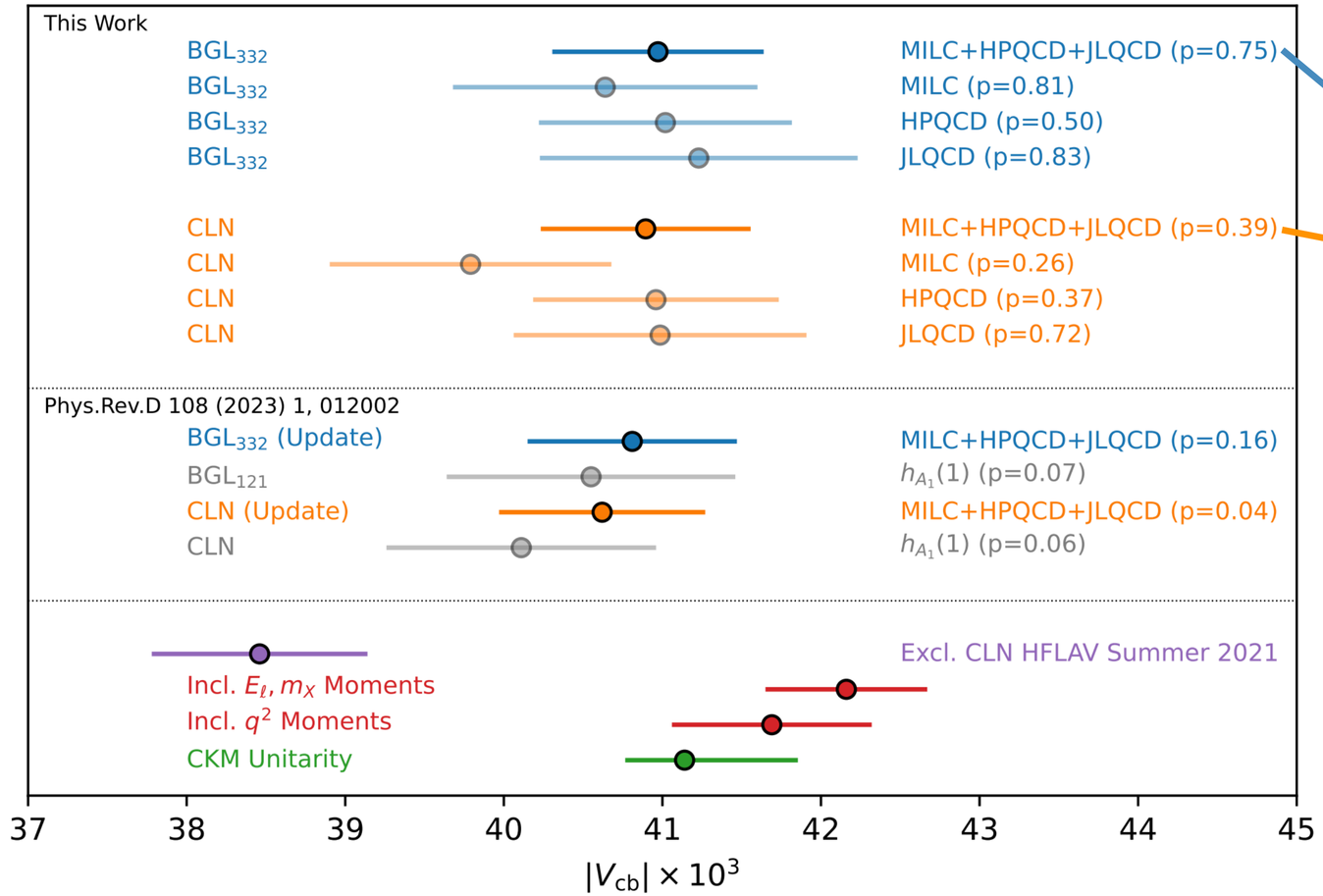


$$\frac{\mathrm{d}\Gamma(\bar{B} \to D^*\ell\bar{\nu}_\ell)}{\mathrm{d}w\,\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_\mathrm{V}\,\mathrm{d}\chi} = \frac{2G_\mathrm{F}^2\eta_\mathrm{EW}^2|V_\mathrm{cb}|^2 m_B^4 m_{\mathrm{D}^*}}{2\pi^4} \times \Big(J_{1s}\sin^2\theta_\mathrm{V} + J_{1c}\cos^2\theta_\mathrm{V}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

Angular Coefficients of $B \to D^* \ell \nu$

arXiv: 2310.20286
preliminary

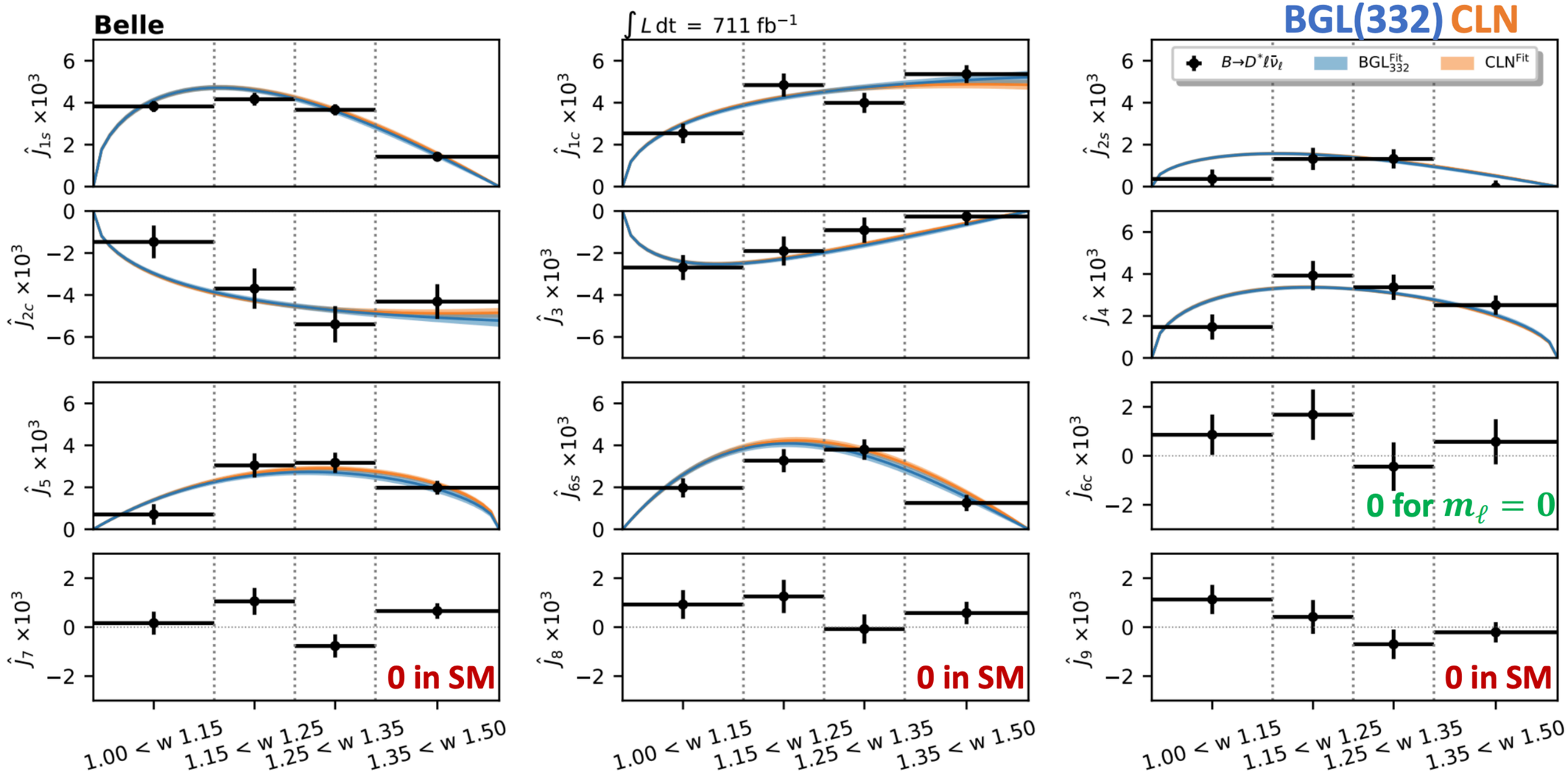
- Obtained $|V_{cb}|$ is in **agreement** with the fit of the one-dimensional partial rates determined from the same data set
- Also **agrees** with the latest & most precise determinations of $|V_{cb}|$ from **inclusive mode**



$$|V_{\rm cb}| = (41.0 \pm 0.3 \pm 0.4 \pm 0.5) \times 10^{-3}\,({\rm BGL}_{332})$$
$$|V_{\rm cb}| = (40.9 \pm 0.3 \pm 0.4 \pm 0.4) \times 10^{-3}\,({\rm CLN})\,,$$

- BGL truncation chose based on nested hypothesis test
- Exp. systematic Uncertainty: limited sample size for migration & eff, branching fraction of D decay, $B \to D^* \ell \nu$ form factor, tagging eff. etc.

Angular Coefficients of $B \to D^* \ell \nu$



Plans for Future $|V_{cb}|$ Measurements at Belle II

- **Belle II Physics Week - Vcb workshop** @ Nov 2023 [indico link]
- Experimentalists + Theorists: discussed crucial proposals on **$|V_{cb}|$ in 3 years & beyond**
- Will wrap into a KEK report (in preparation)

Exclusive

Status

- Latest e**xclusive** $|V_{cb}|$ in Belle's angular analysis is **in agreement with inclusive** determination
- Two out of three **LQCD** groups's results on $B \to D^* \ell \nu$ **form factors** showing **tensions** with both experiments and HQE

Plan

- Measure **angular coefficients / helicity amplitude** with external constraints on normalization (**only shape** measurement, hadronic tagged)
- Separate measurement for **branching fraction** (preferably untagged)
- **Simultaneous analysis** of $B \to D, D^* \ell \nu$ provide better sensitivity

Plans for Future $|V_{cb}|$ Measurements at Belle II

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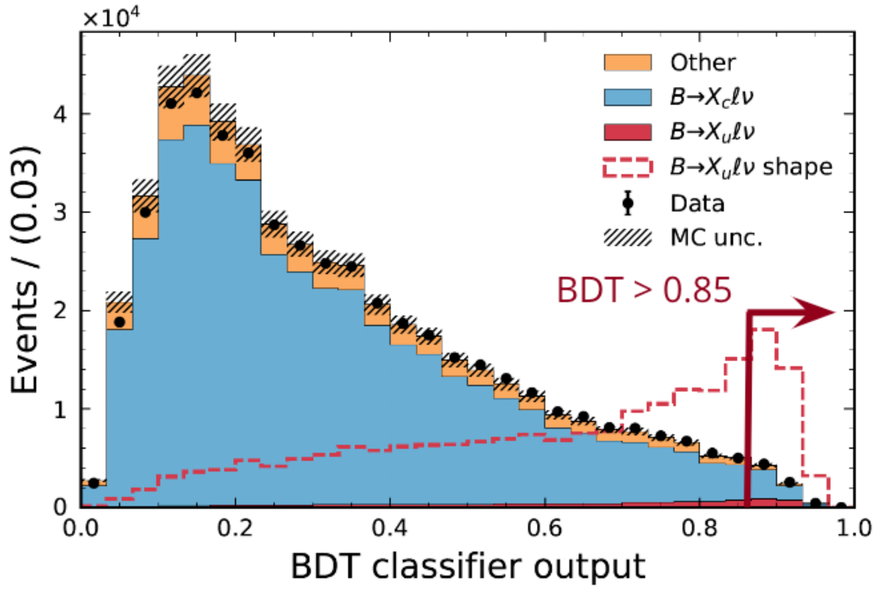
	Exclusive	Inclusive
Status	• Latest e**xclusive** $\|V_{cb}\|$ in Belle's angular analysis is **in agreement with inclusive** determination • Two out of three **LQCD** groups's results on $B \to D^* \ell \nu$ **form factors** showing **tensions** with both experiments and HQE	• Latest inclusive $\|V_{cb}\|$ extraction from **full (q^2, E_l^B, M_X) moments** is consistent with previous incl. determinations • **LQCD** effort of inclusive calculation started
Plan	• Measure **angular coefficients / helicity amplitude** with external constraints on normalization (**only shape** measurement, hadronic tagged) • Separate measurement for **branching fraction** (preferably untagged) • **Simultaneous analysis** of $B \to D, D^* \ell \nu$ provide better sensitivity	• Measure **all kinematic moments simultaneously** for future • **Semi-inclusive** measurements are needed to improve the understanding of "gap" modes • Need to evaluate **QED effects** (provide additional results w/o FSR correction) • Provide differential inclusive spectra to **support LQCD** study

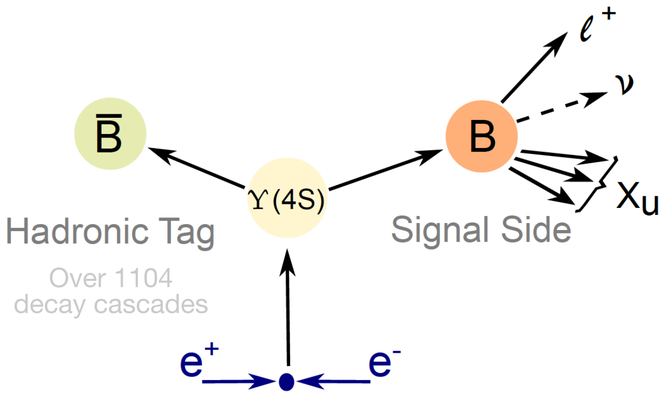
$|V_{ub}|$

First Simultaneous Determination of $|V_{ub}^{\text{incl.}}|$ & $|V_{ub}^{\text{excl.}}|$

PRL 131, 211801 (2023)

- Using **full Belle** dataset of 711 fb^{-1}
- **Hadronic tagging** with Neutral Networks
- Use BDT to suppress backgrounds with 11 training features, e.g. M^2_{miss}, #K$^{\pm}$, #K$_S$, etc.
- Reconstruction strategy inherited from recent Belle's $B \to X_u \ell \nu$ measurements (phase space region $E_\ell^B > 1$ GeV)
  - $\Delta\mathcal{B}$, $|V_{ub}|$ @ PRD 104 , 012008 (2021)
  - Differential spectra @ PRL 127, 261801 (2021)





Can fully assign each final state particle to either the tag side or signal side

=> Allows to reconstruct X_u

Reconstructed kinematic variables

- Hadronic system *X*:

$$p_X = \sum_i (\sqrt{m_\pi^2 + |\mathbf{p_i}|^2}, \mathbf{p_i}) + \sum_i (E_i, \mathbf{k_i})$$

tracks neutrals

- Missing mass squared:

$$M^2_{\text{miss}} = (p_{\Upsilon(4S)} - p_{\text{tag}} - p_X - p_\ell)^2$$

- Leptonic system:

$$q^2 = (p_B - p_X)^2 = (p_\ell - p_\nu)^2$$

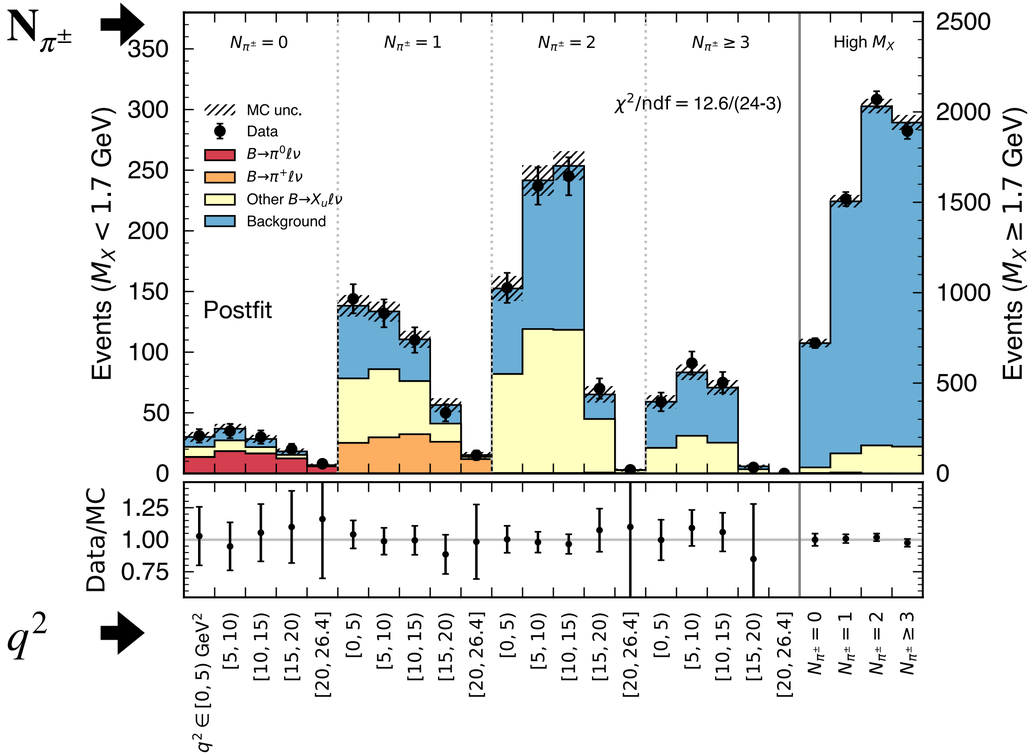
Signal Extraction of Incl. & Excl. $B \to X_u \ell \nu$

PRL 131, 211801 (2023)

- Additional selections on thrust ***T*** of X system in c.m.s to **increase significance** of $B \to \pi \ell \nu$
- Extract signal in $\mathbf{q^2 : N_{\pi^\pm}}$ for $B \to \pi \ell \nu$ and other $B \to X_u \ell \nu$ events
- Simultaneous determination of **signal yields** and $B \to \pi \ell \nu$ **form factor (FF) parameters**
- Systematic uncertainties included via **bin-wise Nuisance para.** θ of each template

$$-2\log\mathscr{L} = -2\log\prod_i \text{Poisson}\left(\eta_{\text{obs}}, \eta_{\text{pred}} \cdot (1 + \epsilon \cdot \theta)\right) + \theta\rho_\theta^{-1}\theta^T + \chi^2_{\text{FF}}$$

Constraints on BCL parameters , input taken from LQCD / LQCD+exp fits in FLAG Review 2021



Normalisations can be linked with isospin relation, or floating separately **(nominal: linked)**

- $B \to \pi^0 \ell \nu$
- $B \to \pi^+ \ell \nu$
- other $B \to X_u \ell \nu$
- all background

Differential decay rates

Acceptance & reco. efficiency

Forward-folding q^2

Signal Extraction of Incl. & Excl. $B \to X_u \ell \nu$

PRL 131, 211801 (2023)

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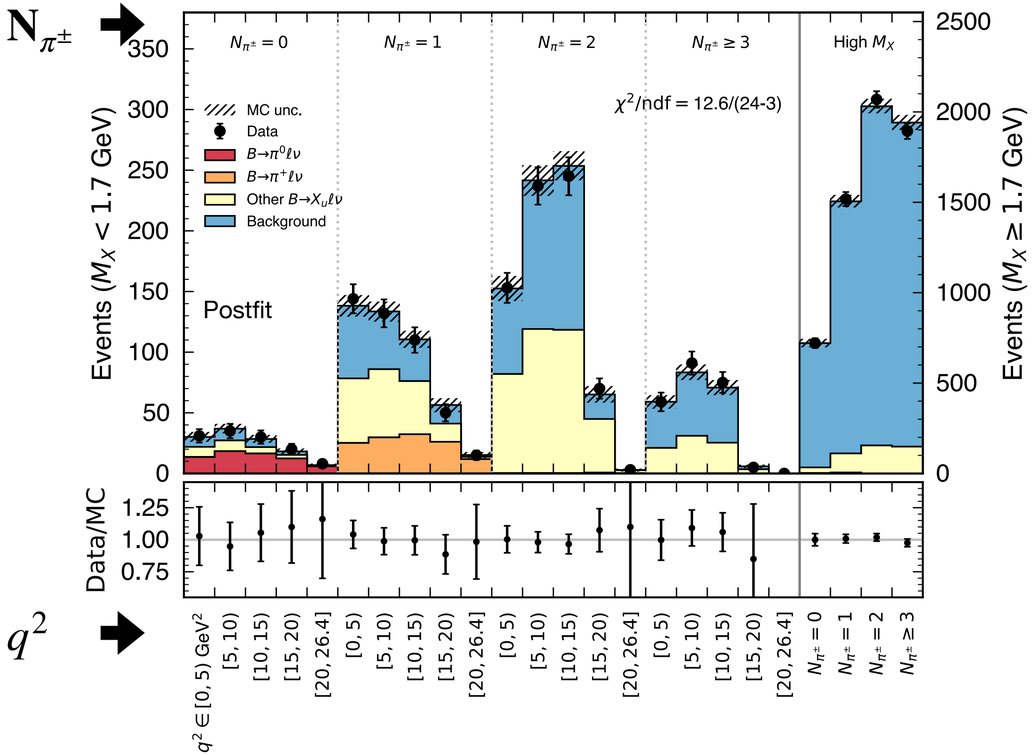

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- $B \to \pi^0 \ell \nu$
- $B \to \pi^+ \ell \nu$
- other $B \to X_u \ell \nu$
- all background

Differential decay rates → Acceptance & reco. efficiency → Forward-folding q^2

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

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

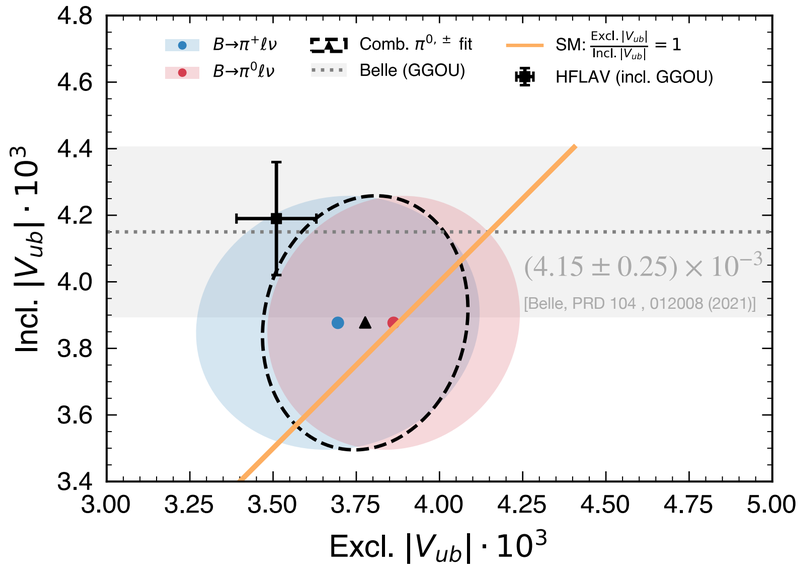
$$\left|V_{ub}^{\text{excl.}}\right| = \sqrt{\frac{\mathscr{B}(B \to \pi \ell \nu)}{\tau_B \cdot \Gamma_{\text{FF}}}}$$

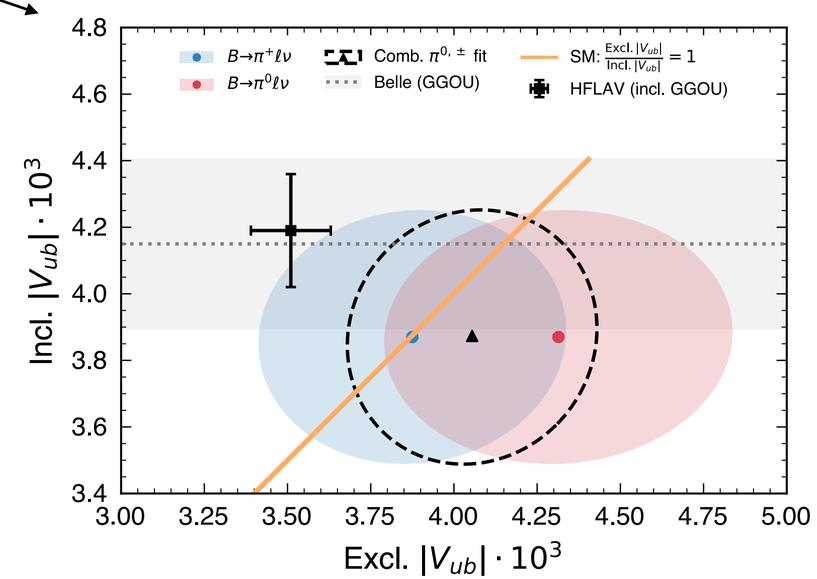
$$\left|V_{ub}^{\text{incl.}}\right| = \sqrt{\frac{\Delta\mathscr{B}(B \to X_u \ell \nu)}{\tau_B \cdot \Delta\Gamma_{\text{GGOU}}}}$$

Results of Incl. & Excl. $|V_{ub}|$

PRL 131, 211801 (2023)

- Various fit scenarios applied:
  - **Combined** or separate $B \to \pi^+ \ell \nu$, $B \to \pi^0 \ell \nu$ (isospin 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.**:**

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

Weighted average of excl. & incl. $(3.84 \pm 0.26) \times 10^{-3}$

This is consistent with CKM global fit (w/o $|V_{ub}|$)**:**

$(3.64 \pm 0.07) \times 10^{-3}$ **within 0.8σ**

Global Fits

$B \to X_s\gamma$ Global Fit:
PRL 127, 102001 (2021)

- Large model dependence in **B meson shape function** (SF) **=> need data-driven treatment**
- Most information in **differential** spectra
- Combining different decay modes (same leading SF) in a **global analysis** is the future

$$\mathrm{d}\Gamma_s = |V_{tb}V_{ts}^*|^2 m_b^2 \left|C_7^{\mathrm{incl}}\right|^2 \int \mathrm{d}k\, \widehat{W}_{77}(E_\gamma; k)\, \widehat{F}(m_B - 2E_\gamma - k) + \cdots$$

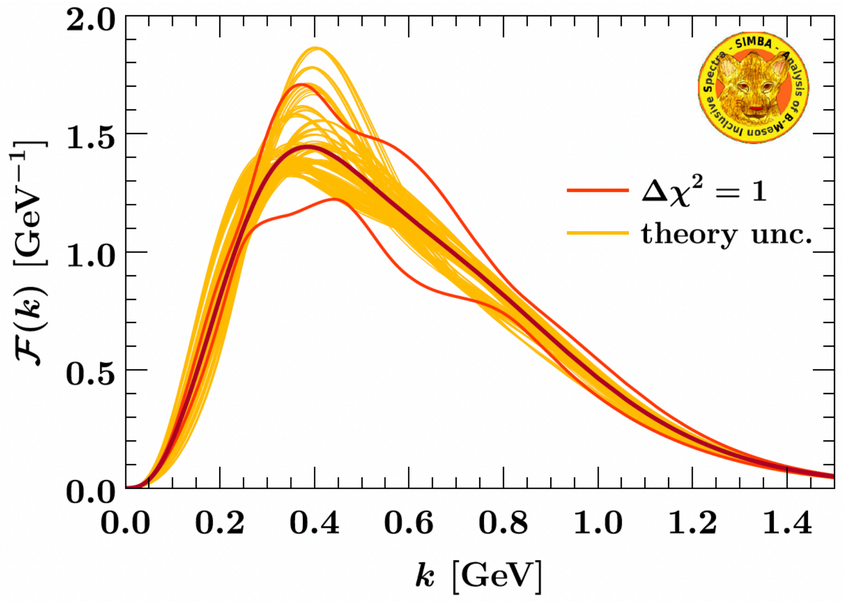
$$\mathrm{d}\Gamma_u = |V_{ub}|^2 \int \mathrm{d}k\, \widehat{W}_u(p_X^-, p_X^+, E_\ell; k) \widehat{F}(p_X^+ - k) + \cdots$$

- Fit parameters: $|V_{tb}V_{ts}^*|^2 m_b^2$, $|V_{ub}|^2$, $\widehat{F}(\lambda x) = \frac{1}{\lambda}\left[\sum_{n=0}^{\infty} c_n f_n(x)\right]^2$
  - Theory Input: $\widehat{W}_i(\ldots; k)$ computed to (N)NNL'+NNLO in 1S scheme
  - Factorized shape function:

$$S(\omega, \mu_\Lambda) = \int \mathrm{d}k\, \widehat{C}_0(\omega - k, \mu_\Lambda)\, \widehat{F}(k)$$

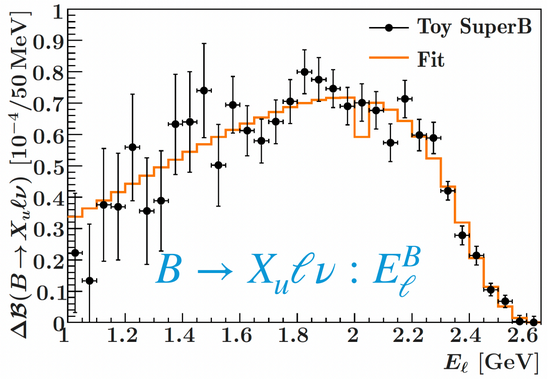
$\widehat{F}(k)$ nonperturbative part
- Determines peak region
- Fit from data

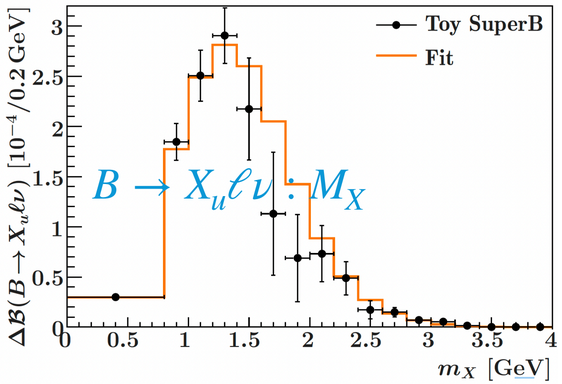
$\widehat{C}_0(\omega, \mu_\Lambda)$ perturbative part
- Generates perturbative tail with correct μ_Λ dependence

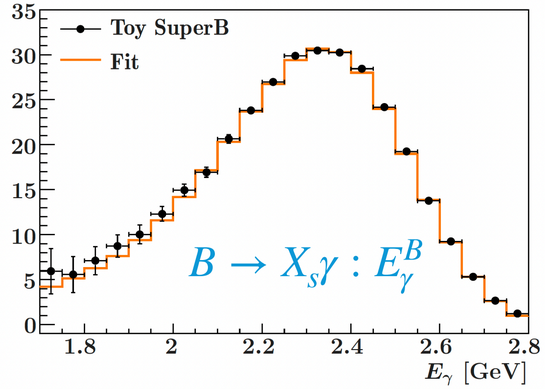


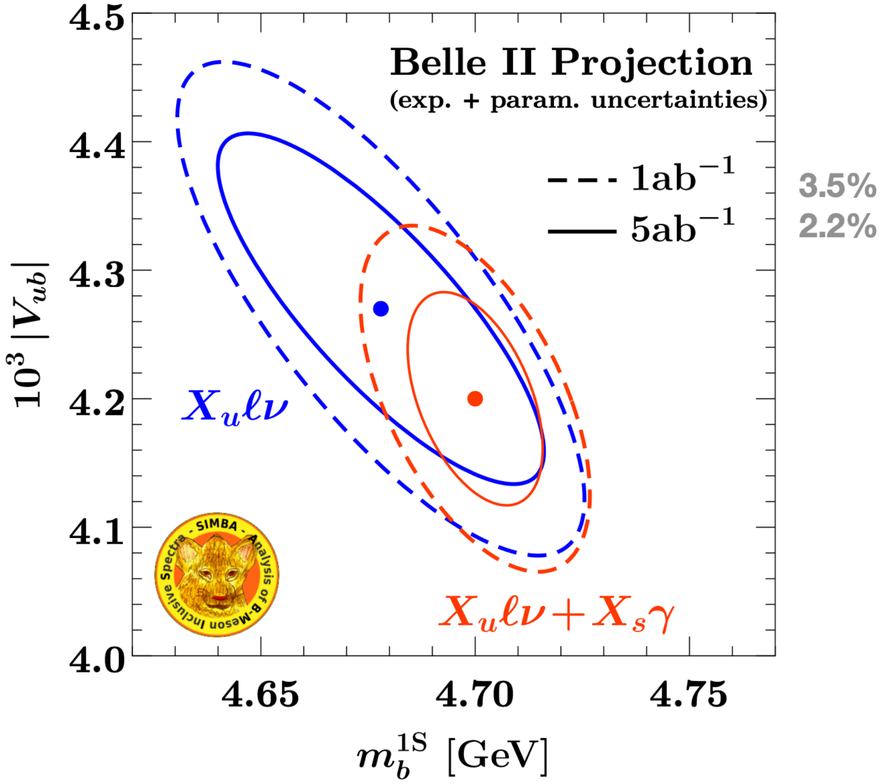
Global Fits Prospects on $B \to X_s\gamma$ + $B \to X_u\ell\nu$

- Theory
  - NLL' + NLO
  - ignore subleading SFs
- Toy study
  - Generate mX, El, and Eɣ from theory
  - Smeared from uncertainties and correlations inspired by BaBar hadronic tag analysis, Belle II hadronic tagging efficiency is much better by now
  - Target lumi: 1/ab, 5/ab
  - **Caveats:**
    - No resolution effects considered
    - No theory uncertainties included (!)
    - Not done with Belle II MC









Credit: F. Bernlochner

Global Analysis

Differential Information

$\bar{B} \to X_u \ell \bar{\nu}_\ell$: E_ℓ, m_X, q^2

+

$\bar{B} \to X_s \gamma$: E_γ

+

$\bar{B} \to X_s \ell\ell$: q^2

+

$\bar{B} \to X_c \ell \bar{\nu}_\ell$: E_ℓ, q^2

+

$\bar{B} \to X \tau \bar{\nu}_\tau$: q^2

Global Analysis

$|V_{ub}|$ → Incl. versus Excl. Problem (3.4 σ)

b-Quark momentum distribution → Unknown distribution, equivalent to **Proton PDF for LHC**

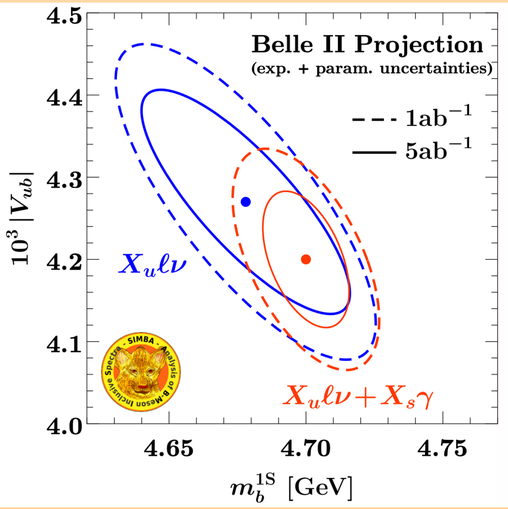
$|C_7|$, C_9, C_{10} → Search for **New Physics**

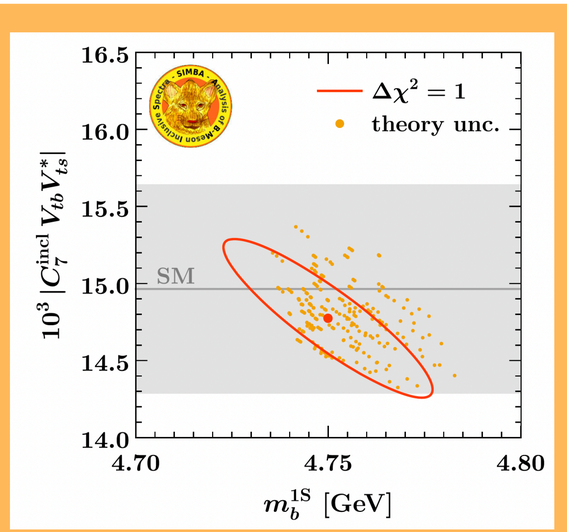
m_b → **Fundamental parameter** of the Standard Model

$|V_{cb}|$ → Incl. versus Excl. Problem (2.4 σ)

R(X) → 4 σ difference in semi-tauonic decays

$$R(X) = \frac{\mathcal{B}(\bar{B} \to X \tau \bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to X \ell \bar{\nu}_\ell)}$$





PRL 127, 102001 (2021)

Credit: F. Bernlochner

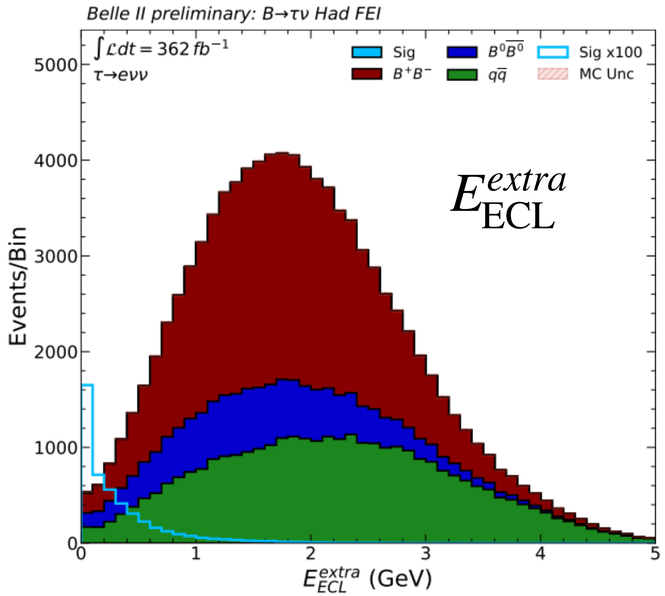
Search for $B \to \tau\nu$ at Belle II

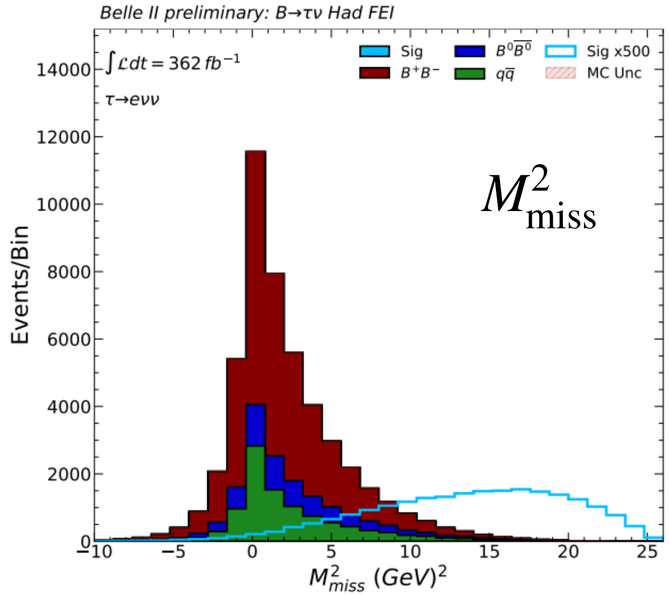
- Sensitivity based on a data set of 362 fb^{-1} studied with MC simulations
- Full analysis chain validated in pseudo-data
- With optimized signal selection: statistical uncertainty 37% (2.8σ from null hypothesis), systematic uncertainty ~13 %
- Results expected to be released in **2024**

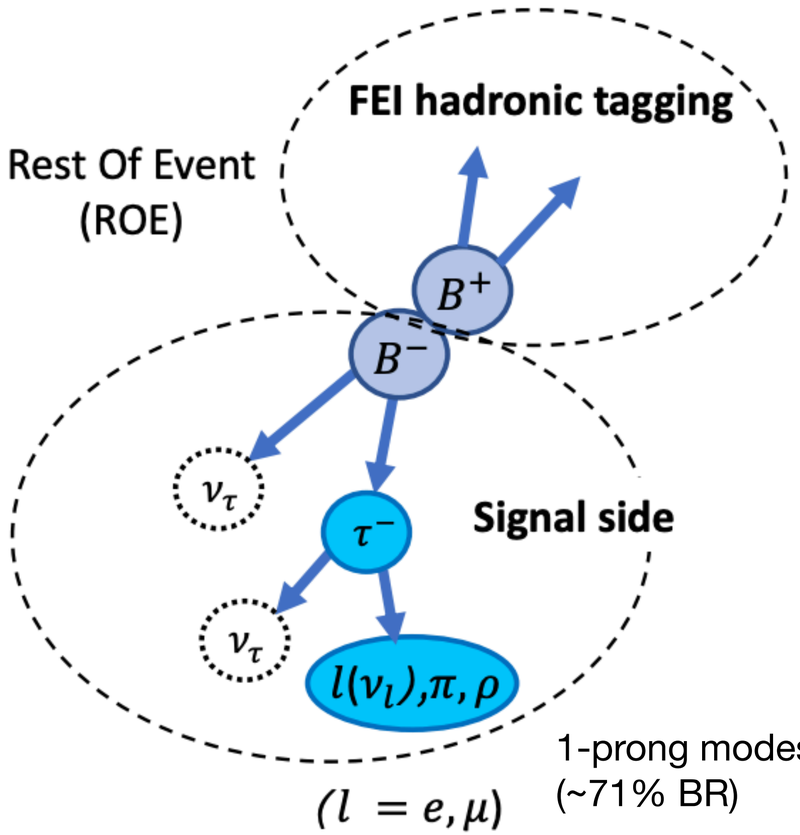
Most discriminating variables for signal:

- E_{ECL}^{extra}, **the extra energy not associated with the** B_{tag} **and** B_{sig} **(Rest of Event).**
- $M_{miss}^2 = E_{miss}^2 - p_{miss}^2$, **squared magnitude of the four-momentum** p_{miss}.

A data-driven correction is applied to both the variables to correct the distributions.





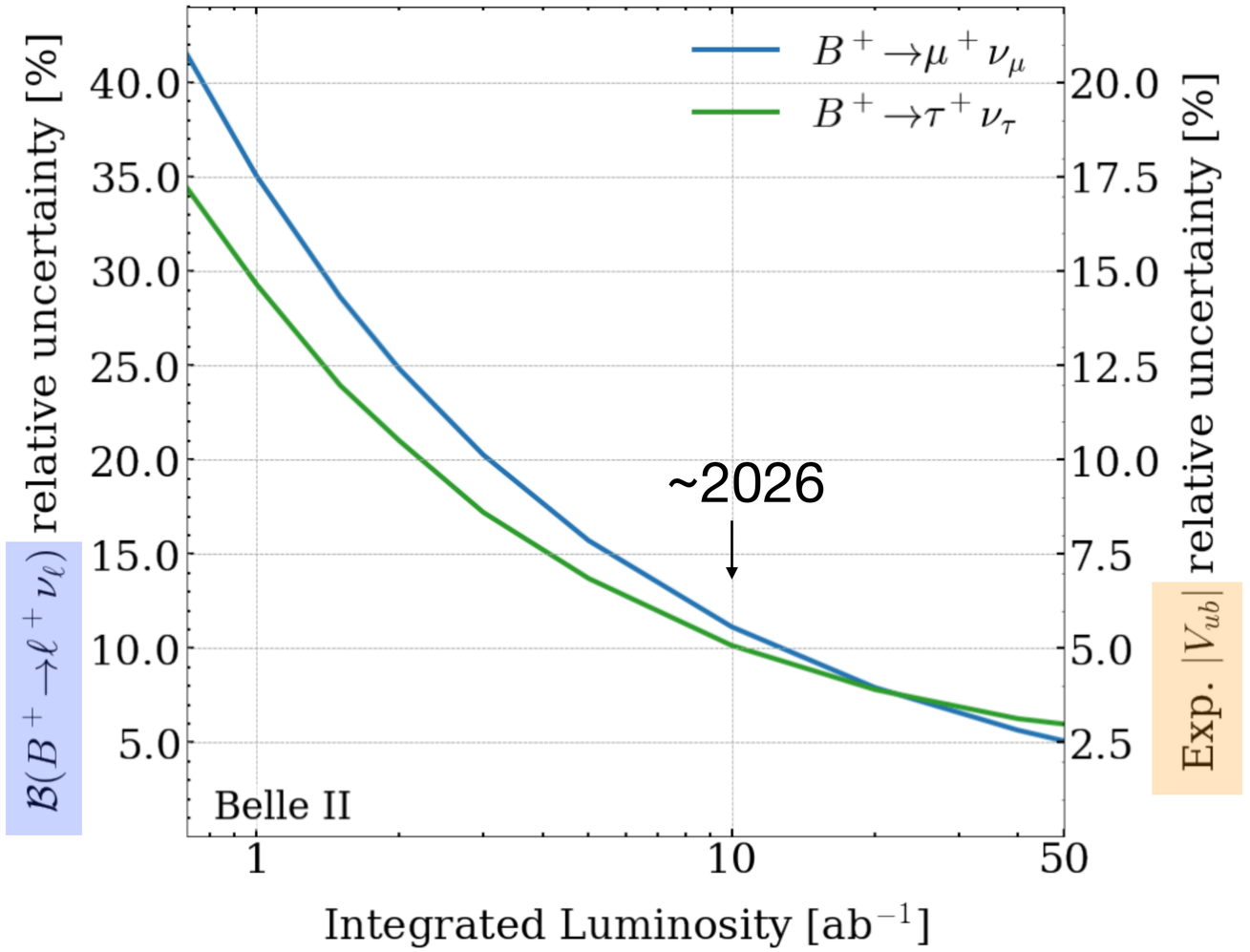


1-prong modes
(~71% BR)

→ No Extra Tracks (from IP)

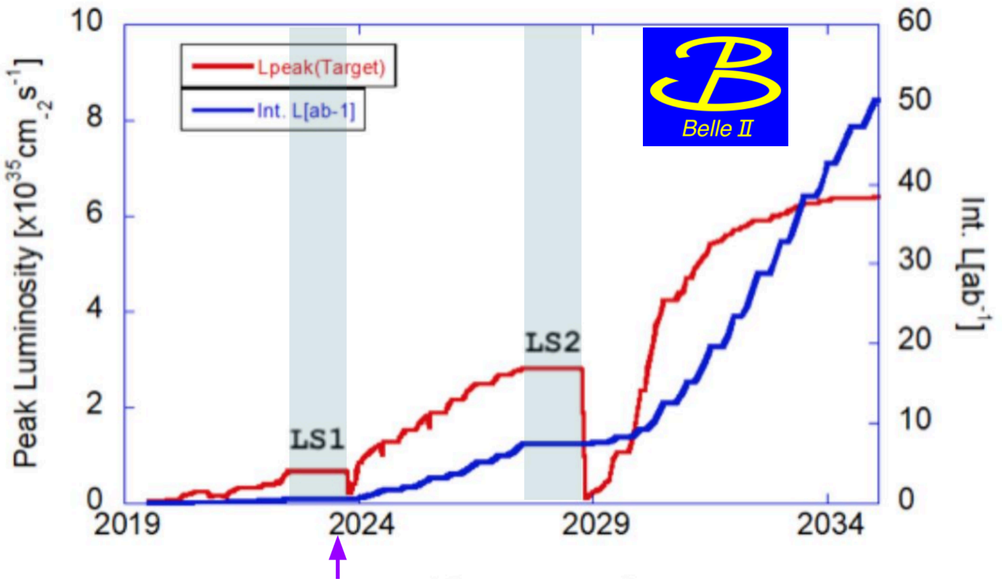
Expected Sensitivity of Leptonic $|V_{ub}|$ on Belle II

- Expected event yields and precisions on the branching fraction and determined $|V_{ub}|$
- Ultimate precision on $|V_{ub}|$ at ~2.5% level from $B \to \tau\nu, B \to \mu\nu$

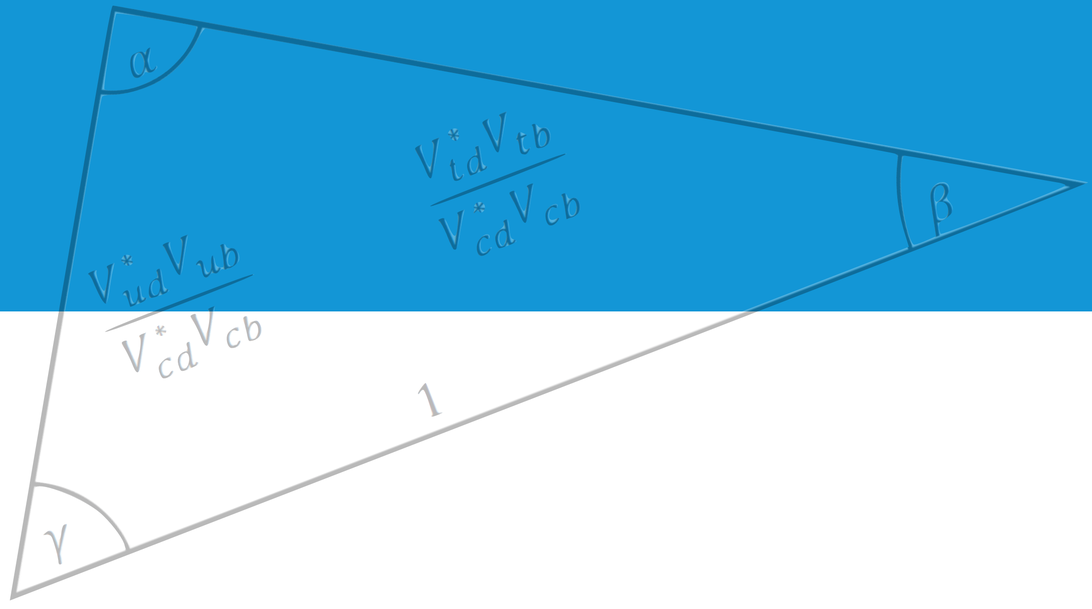


Summary

- Several new results on **$|V_{xb}|$** measured recently at Belle and Belle II
- Useful discussions in Belle II Physics week trigger a clear plan for **$|V_{cb}|$ in 3 years**
- Continuous efforts from **experiment** and **theory** are still needed
- Expected **upcoming** $|V_{xb}|$ results in **2024 spring**:
  - Had. tagged $B \to \pi \ell \nu$, $B \to \rho \ell \nu$
  - Untagged simultaneous $B \to \pi \ell \nu$, $B \to \rho \ell \nu$
  - Had. tagged $B \to \tau \nu$
  - Had. tagged $B \to \mu \nu$ [Belle+Belle II]



THANK YOU



Backup: Angular Coefficients of $B \to D^* \ell \nu$

arXiv: 2310.20286
preliminary

$$A_{\rm FB} = \frac{3}{2} \frac{(J_{6c} + 2J_{6s})}{3J_{1c} - J_{2c} + 2(3J_{1s} - J_{2s})},$$

$$F_L(D^*) = \frac{(3J_{1c} - J_{2c})}{3J_{1c} - J_{2c} + 2(3J_{1s} - J_{2s})},$$

$$S_3 = \frac{1}{\pi} \frac{4J_3}{3J_{1c} - J_{2c} + 2(3J_{1s} - J_{2s})},$$

$$S_5 = \frac{3J_5}{3J_{1c} - J_{2c} + 2(3J_{1s} - J_{2s})},$$

$$S_7 = \frac{3J_7}{3J_{1c} - J_{2c} + 2(3J_{1s} - J_{2s})},$$

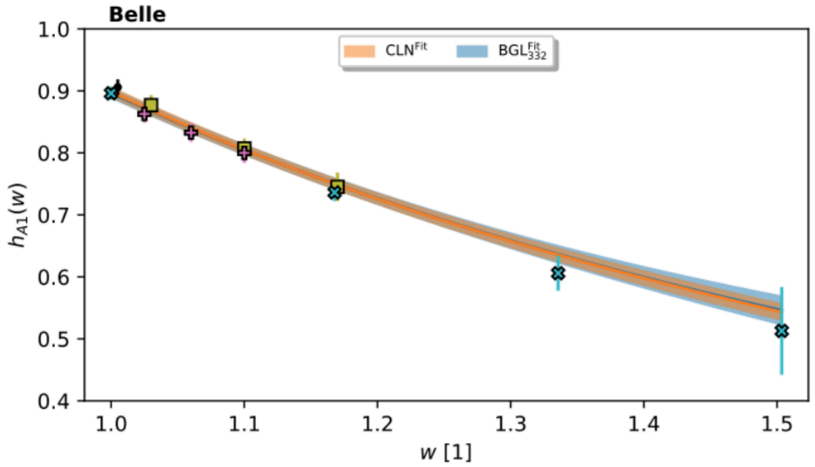
$$S_9 = \frac{1}{\pi} \frac{4J_9}{3J_{1c} - J_{2c} + 2(3J_{1s} - J_{2s})},$$

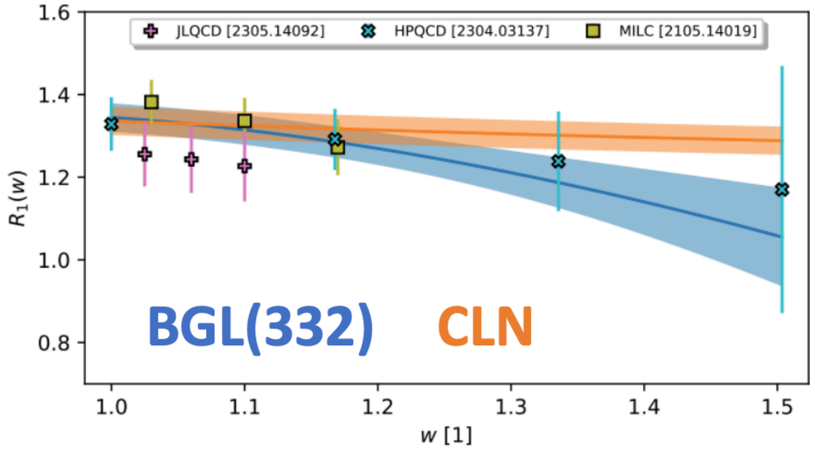
TABLE VII. The fitted coefficients for the BGL fit described in the text.

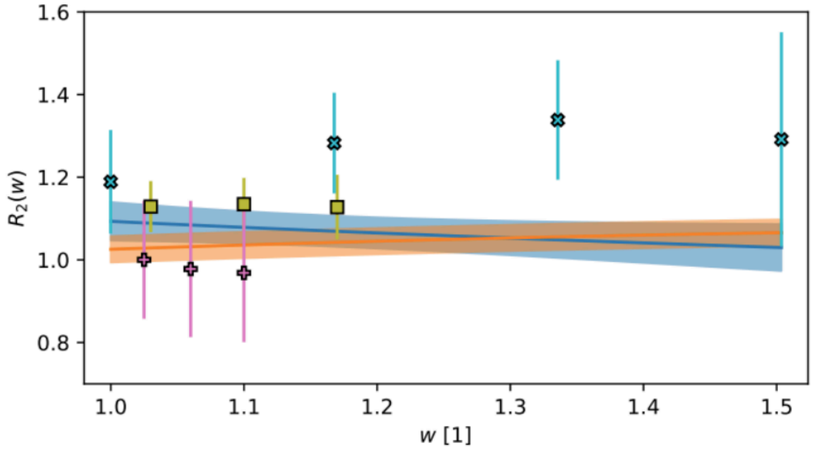
	Value	Correlation								
$a_0 \times 10^2$	2.68 ± 0.06	1.00	0.03	-0.11	0.17	0.00	-0.02	0.08	-0.04	-0.19
$a_1 \times 10^2$	-2.65 ± 2.35	0.03	1.00	-0.67	-0.01	0.17	-0.03	0.09	-0.03	-0.10
$a_2 \times 10^2$	-145.18 ± 87.35	-0.11	-0.67	1.00	0.03	-0.02	-0.03	0.01	-0.05	-0.03
$b_0 \times 10^2$	1.30 ± 0.01	0.17	-0.01	0.03	1.00	-0.02	0.02	0.02	-0.03	-0.50
$b_1 \times 10^2$	1.30 ± 0.66	0.00	0.17	-0.02	-0.02	1.00	-0.66	0.59	-0.46	-0.28
$b_2 \times 10^2$	-11.50 ± 22.40	-0.02	-0.03	-0.03	0.02	-0.66	1.00	-0.45	0.40	-0.04
$c_1 \times 10^2$	-0.25 ± 0.16	0.08	0.09	0.01	0.02	0.59	-0.45	1.00	-0.82	-0.32
$c_2 \times 10^2$	0.78 ± 3.29	-0.04	-0.03	-0.05	-0.03	-0.46	0.40	-0.82	1.00	0.05
$\lvert V_{cb} \rvert \times 10^3$	40.97 ± 0.67	-0.19	-0.10	-0.03	-0.50	-0.28	-0.04	-0.32	0.05	1.00

Backup: Angular Coefficients of $B \to D^* \ell \nu$

arXiv: 2310.20286
preliminary







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

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

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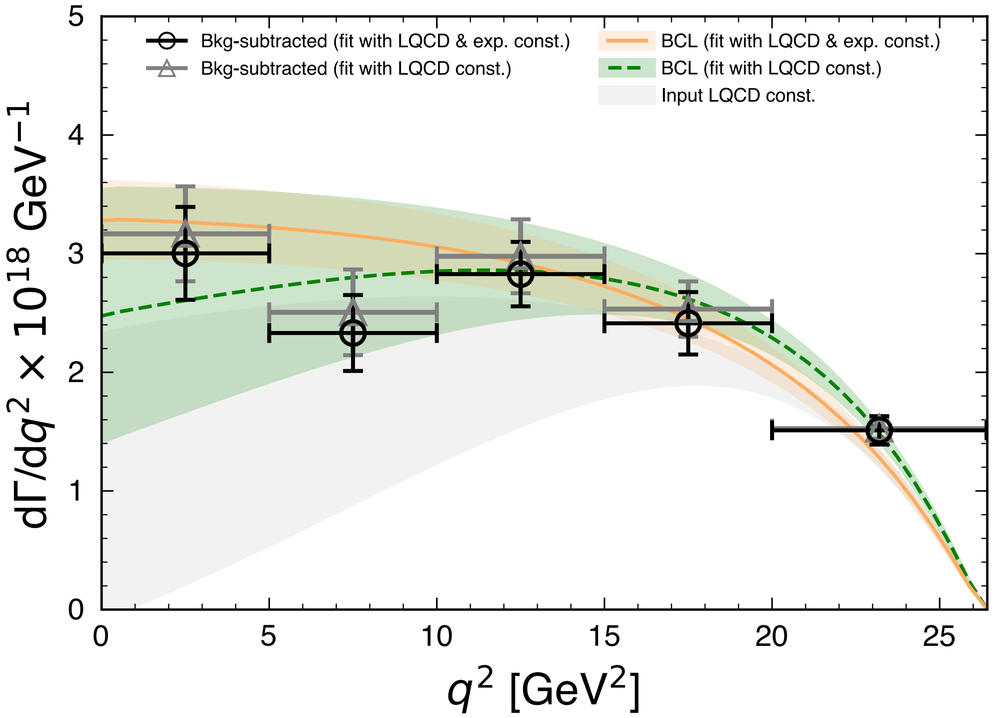
q^2 spectra with **fitted BCL para.** (linked $\pi^{0,\pm}$)



Points: subtract other $B \to X_u \ell \nu$ and background in data, and apply unfolding + eff. correction

Fitted BCL parameters (LQCD + exp.)

	$\lvert V_{ub}\rvert \times 10^3$	a_0^+	a_1^+	a_2^+	a_0^0	a_1^0
Central	3.777	0.414	-0.493	-0.297	0.500	-1.426
Uncertainty	0.309	0.014	0.053	0.180	0.023	0.054
$\lvert V_{ub}\rvert$	1.000	-0.452	-0.168	0.232	-0.109	-0.105
a_0^+		1.000	0.151	-0.451	0.259	0.142
a_1^+			1.000	-0.798	-0.096	0.214
a_2^+				1.000	0.012	-0.097
a_0^0					1.000	-0.451
a_1^0						1.000

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

Leading Systematic Uncertainties

Sources	Relative Syst. Uncertainty
Exclusive mode	$\mathcal{B}(B \to \pi \ell \nu)$
Tagging efficiency	4.1%
$B \to X_u \ell \nu$ modelling	3.5%
$B \to X_c \ell \nu$ modelling	1.2%
Inclusive mode	$\Delta\mathcal{B}(B \to X_u \ell \nu)$
$B \to X_u \ell \nu$ modelling	10.9%
Fragmentation	5.3%
$B \to X_c \ell \nu$ modelling	2.8%

Hybrid Model of $B \to X_u \ell \nu$

PRD 104 , 012008 (2021)

Hybrid MC is a **combination** of **resonances** (exclusive decays) and **non-resonant** contribution in the inclusive $B \to X_u \ell \nu$ decays

- EvtGen simulation:

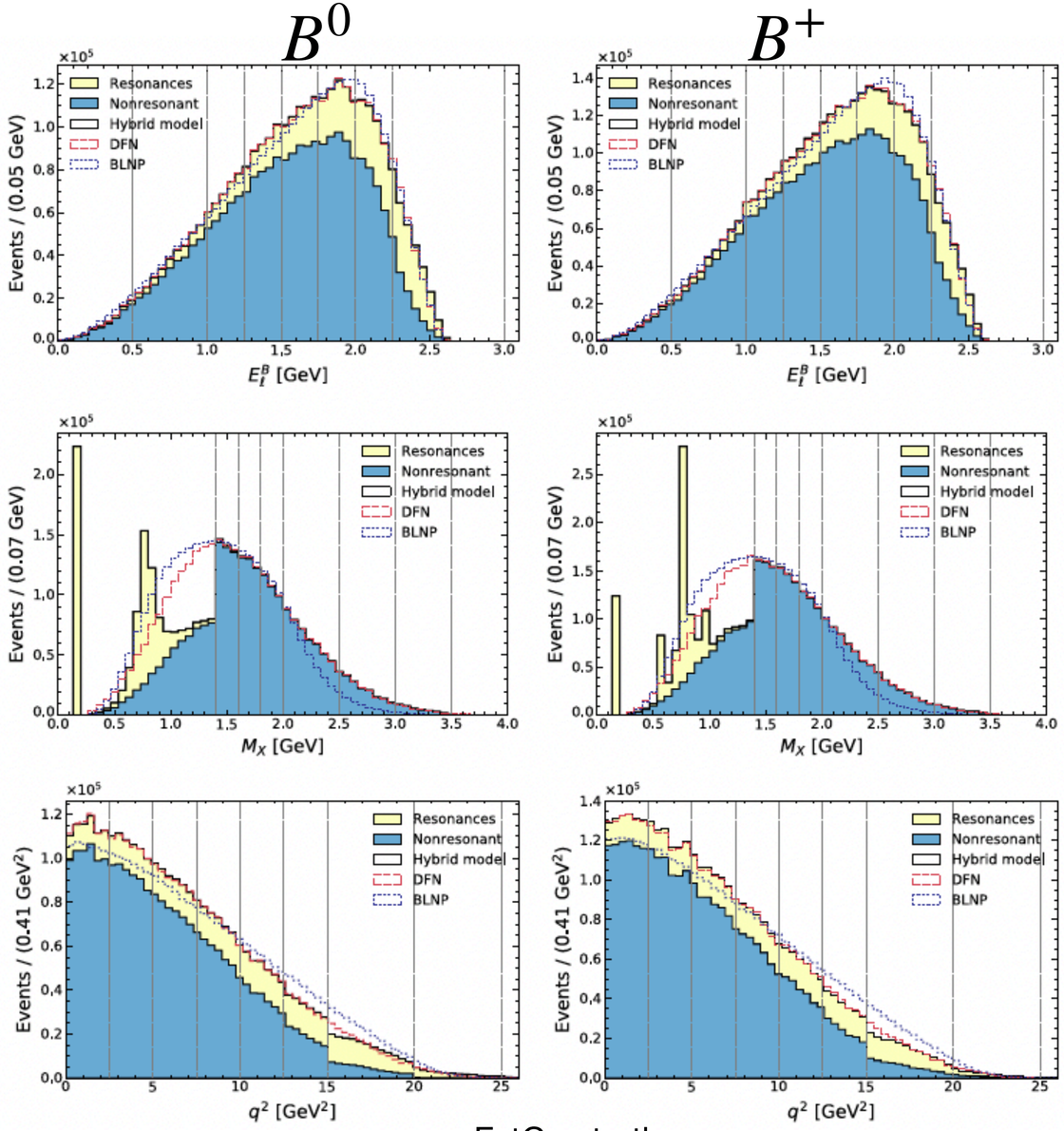
(1) exclusive modes $B \to (\pi, \rho, \omega, \eta^{(\prime)}) \ell \nu$ with latest WA form factors & branching fractions

(2) fully inclusive $B \to X_u \ell \nu$ (only non-resonant shapes, e.g. BLNP, GGOU)

- Calculate hybrid weights to mix resonance & non-res. in **3D binning of** (q^2, E_ℓ^B, M_X) to recover total $\mathcal{B}(B \to X_u \ell \nu)$ in each bin

$$H_i = R_i + \omega_i N_i$$

- Systematic uncertainties include the impact from exclusive FFs & BRs, total $\mathcal{B}(B \to X_u \ell \nu)$, inclusive models



EvtGen truth