Precision Measurements of Weak Interaction Parameters

CKM and CP Violation at Belle and Belle II

Ansu Johnson
on behalf of the Belle II Collaboration

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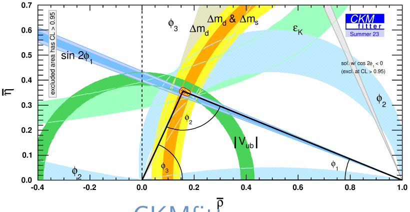
CKM MATRIX & UNITARITY TRIANGLE

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

- Overconstrain UT apex through diverse measurements
- goal: precise measurement of all UT angles and sides
- Test the Standard Model and probe BSM
    - Tree-dominated decays: Provide clean SM constraints
    - Loop-dominated decays: Sensitive to BSM contributions



CKMfitter

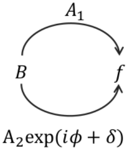
ϕ_1	$(22.5^{+0.5}_{-0.4})^\circ$
ϕ_2	$(86.2^{+3.9}_{-3.5})^\circ$
ϕ_3	$(65.9^{+3.3}_{-3.5})^\circ$
$\lvert V_{cb}\rvert$	$(41.6^{+0.2}_{-0.6}) \times 10^{-3}$
$\lvert V_{ub}\rvert$	$(3.73^{+0.04}_{-0.05}) \times 10^{-3}$

CHARGE-PARITY VIOLATION (CPV)

$$V_{CKM} = \begin{bmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ \lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(\rho - i\eta) & -A\lambda^2 & 1 \end{bmatrix}$$

DIRECT CPV

- Originates from interference between two amplitudes



INDIRECT CPV

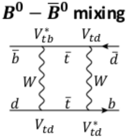
- Measured through interference between mixing and decay
- Time-dependent CPV (TDCPV)

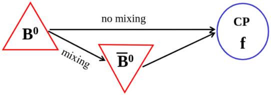
$$\mathbf{A_{CP}^{B\to f}(\Delta t)} \equiv \frac{\mathbf{\Gamma\left(B^0(\Delta t) \to f\right) - \Gamma\left(\bar{B}^0(\Delta t) \to f\right)}}{\mathbf{\Gamma\left(B^0(\Delta t) \to f\right) + \Gamma\left(\bar{B}^0(\Delta t) \to f\right)}}$$

$$= \mathbf{S} \cdot \sin\left(\mathbf{\Delta m_d \Delta t}\right) - \mathbf{C} \cdot \cos\left(\mathbf{\Delta m_d \Delta t}\right)$$

S = $|\sin(2\phi)|$ = Mixing induced CPV

C = Direct CPV

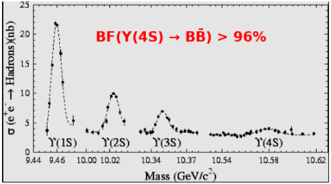


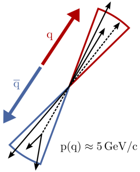


Angle	Relation	Measurement Channels	Tree/Loop	CPV Type
$\phi_2(\alpha)$	$\arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right)$	$B^0 \to \pi\pi$, $B^0 \to \rho^+\rho^-$	Mixed (Tree/Loop)	TDCPV
$\phi_3(\gamma)$	$\arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$	$B^+ \to D^0K^+$ with various D^0 decays	Tree-dominated	Direct

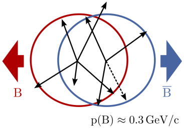
B PHYSICS AT BELLE II

- e^+e^- collision at $\Upsilon(4S)$ [10.58 GeV]
  - Coherent production of $B\bar{B}$ pairs
  - Clean environment
- Dominant background: $e^+e^- \to q\bar{q}$
- Spherical $B\bar{B}$ events can be discriminated from jet-like $q\bar{q}$
- Continuum suppression using Multivariate Analysis (MVA)
- Kinematic constraints: well-known beam energy
  - ΔE: Reconstructed B and beam energy difference
  - $M_{\rm bc}$: Beam constrained mass

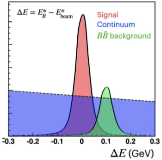


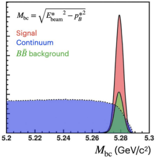


$e^+e^- \to q\bar{q} \quad (q \in \{u,d,s,c\})$



$e^+e^- \to \Upsilon(4S) \to B\bar{B}$





FULL EVENT INTERPRETATION (FEI)

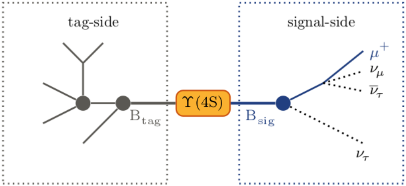
- Essential tool for decays with missing kinematic information
  - eg: Decay involving neutrinos
- FEI algorithm reconstructs second B meson (B_{tag}) in $\sim$ 10k channels
- Infer kinematics of signal B using well known initial state of $\Upsilon(4S)$

$$\mathrm{p}_{\mathrm{e}^+} + \mathrm{p}_{\mathrm{e}^-} = \mathrm{p}_{\mathrm{B}_{\mathrm{sig}}} + \mathrm{p}_{\overline{\mathrm{B}}_{\mathrm{tag}}}$$

Purity →

← **Efficiency**

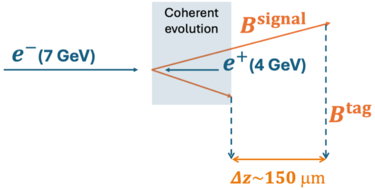
Inclusive	**Hadronic**
$B \to$ anything	$B \to$ hadrons
$\epsilon \approx \mathcal{O}(100\%)$	$\epsilon \approx \mathcal{O}(0.1\%)$



Computing and Software for Big Science (2019)

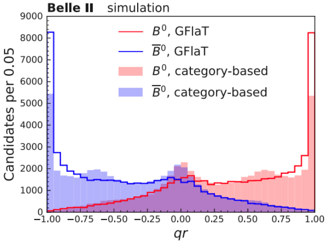
FLAVOR TAGGING

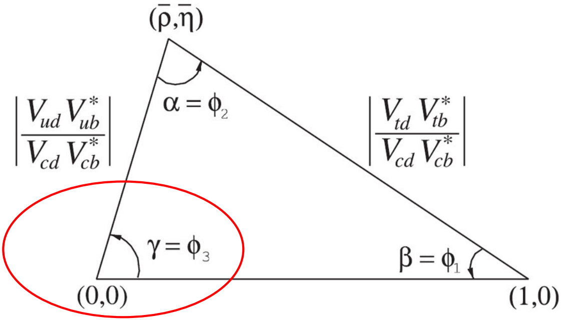
- Distinguish between B^0 and $\bar{B}^0$
- Signatures of flavor-specific decays grouped into 13 categories
- Quantum correlation allows identification of signal B flavor based on tag B
- $\epsilon = (31.68 \pm 0.45)\%$



Graph-neural-network flavor tagging (GFlaT) PhysRevD.110.012001

- Updated from category-based algorithm
- Improved performance by accounting for correlations between final-state particles
- $\epsilon = (37.40 \pm 0.43 \pm 0.36)\%$
  - 18% increase in efficiency

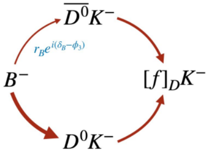



$(\bar{\rho},\bar{\eta})$
$\alpha = \phi_2$
$\left|\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right|$
$\left|\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}\right|$
$\gamma = \phi_3$
$\beta = \phi_1$
(0,0)
(1,0)

ANGLE $\phi_3(\gamma)$

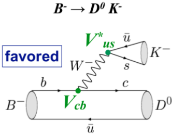
ϕ_3 is the phase between $b \to u\bar{c}s$ and $b \to c\bar{u}s$ transitions

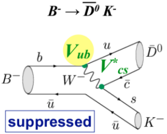
Accessible using $B \to DK$



$$\frac{A^{\text{suppr.}}(B^- \to \bar{D}^0 K^-)}{A^{\text{favor.}}(B^- \to D^0 K^-)} = r_{\mathrm{B}} e^{i(\delta_{\mathrm{B}} - \phi_3)}$$

- Common final states give access to phase via interference
- Tree level: No (large) BSM
- SM benchmark





Method	Decay Mode
GLW	$D^0 \to K^+K^-, K^0_s\pi^0$ (CP eigenstates)
BPGGSZ	Self-conjugate multi-body decay, e.g., $D^0 \to K^0_s h^+ h^-$
GLS	$D^0 \to K^0_s K^\pm \pi^\mp$ (singly Cabibbo-suppressed decays)
ADS	$D^0 \to K^\pm \pi^\mp$

ϕ_3: Belle + Belle II combination

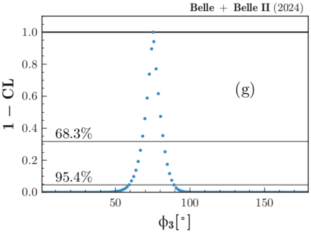
B decay	D decay	Method	Data set (Belle + Belle II)[fb^{-1}]
$B^+ \to Dh^+$	$D \to K_s^0\pi^0, K^-K^+$	GLW	711 + 189 **BelleII**
$B^+ \to Dh^+$	$D \to K^+\pi^-, K^+\pi^-\pi^0$	ADS	711 + 0
$B^+ \to Dh^+$	$D \to K_s^0K^-\pi^+$	GLS	711 + 362 **BelleII**
$B^+ \to Dh^+$	$D \to K_s^0h^-h^+$	BPGGSZ (m.i.)	711 + 128 **BelleII**
$B^+ \to Dh^+$	$D \to K_s^0\pi^-\pi^+\pi^0$	BPGGSZ (m.i.)	711 + 0
$B^+ \to D^*K^+$	$D^* \to D\pi^0, D \to K_s^0\pi^0, K_s^0\phi,$ $K_s^0\omega, K^-K^+, \pi^-\pi^+$	GLW	210 + 0
$B^+ \to D^*K^+$	$D^* \to D\pi^0, D\gamma, D \to K_s^0\pi^-\pi^+$	BPGGSZ (m.d.)	605 + 0

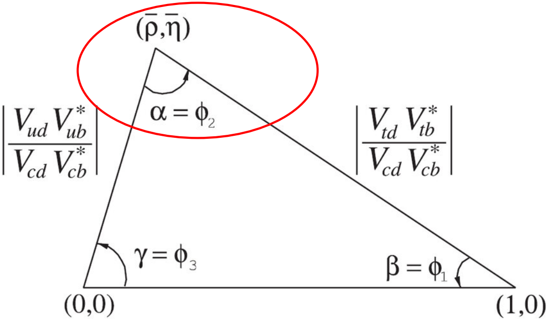
- **First combination of all Belle and Belle II ϕ_3 measurements**
- 59 input observables and 18 free parameters
- Belle + Belle II is improving the precision!

JHEP10(2024)143

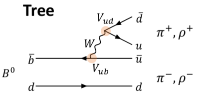
Experiment	ϕ_3 (°)
Belle + Belle II	(75.2 ± 7.6)
LHCb LHCb-CONF	(64.6 ± 2.8)

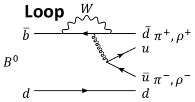
Dominated by LHCb

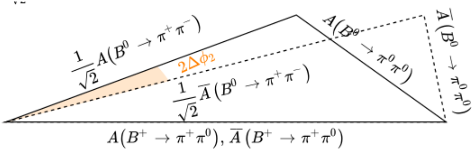



$(\bar{\rho},\bar{\eta})$
$\alpha = \phi_2$
$\left|\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right|$
$\left|\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}\right|$
$\gamma = \phi_3$
$\beta = \phi_1$
(0,0)
(1,0)

EXTRACTION OF ϕ_2 : ISOSPIN ANALYSIS







- TDCPV measurement
- $b \to u\bar{u}d$: sensitive to ϕ_2
- $b \to d$ loop contributions add an extra phase $\Delta\phi_2$
- Interference of tree and loop: $S = \sin(2\phi_2 + 2\Delta\phi_2), \mathrm{C} \neq 0$

Key Observables:

$\pi^+\pi^-, \rho^+\rho^-$	BF, S, C
$\pi^+\pi^0, \rho^+\rho^0$	BF, A_{CP}
$\pi^0\pi^0, \rho^0\rho^0$	BF, A_{CP} or C S (only for $\rho^0\rho^0$)

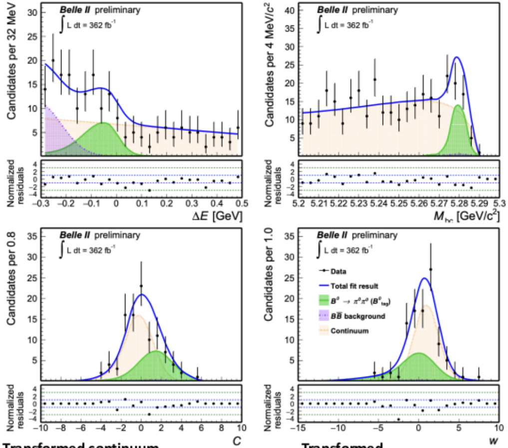
- Isospin symmetry allows for separating tree and penguin contributions
- Determining ϕ_2 from $B \to \pi\pi$ requires BFs and A_{CP} of $B^0 \to \pi^+\pi^-$, $B^+ \to \pi^+\pi^0$, $B^0 \to \pi^0\pi^0$
- $\pi^0\pi^0, \rho^+\rho^0, \rho^+\rho^-$ requires π^0 reconstruction:
  - Belle II has an advantage.
- $\rho\rho$ with smaller loop contribution dominates ϕ_2 precision

ϕ_2 : $B^0 \to \pi^0\pi^0$

- Experimentally challenging: 4 photons and no tracks
- Updated measurements of BF and A_{CP} with full Run-1 statistics:
    - GFlat for flavor tagging
    - MVA dedicated for photon selections
- Fit to four variables

	$\mathbf{BF} \times 10^{-6}$	A_{CP}
BelleII	$\mathbf{1.26 \pm 0.20 \pm 0.12}$	$\mathbf{-0.06 \pm 0.30 \pm 0.05}$
WA	1.59 ± 0.26	0.30 ± 0.20

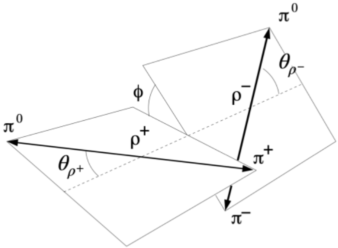
- World best BF
- A_{CP} comparable with WA
- Paper in preparation



Transformed continuum suppression output

Transformed wrong flavor tag probability

$\phi_2 : B^0 \to \rho^+\rho^-$

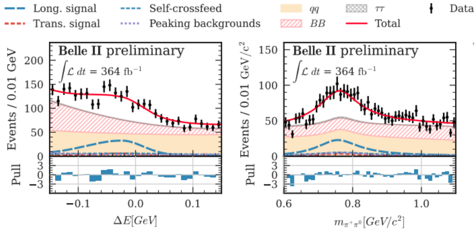


- Small contribution from loops: gives most stringent constraints on ϕ_2
- Reconstruction: $\rho \to \pi^+(\pi^0 \to \gamma\gamma)$
- MVA to identify real photons in π^0
- $q\bar{q}$ suppressed by TabNet (arxiv:1908.07442)
- *Psuedoscalar* $\to$ *Vector Vector* decay:
  - Longitudinal and two transverse polarization states
  - The fraction of longitudinal polarization f_L determines the sensitivity of the CPV parameters
  - f_L is extracted from the helicity angle θ_ρ

$$f_L = \frac{\mathcal{B}(\text{Long.})}{\mathcal{B}(\text{Long.}) + \mathcal{B}(\text{Trans.})}$$

$\phi_2 : B^0 \to \rho^+\rho^-$

- Improved precision by GFlat flavor-tagger and better selection criteria
- Fit to 6 observables to extract $\mathcal{B}$ and f_L

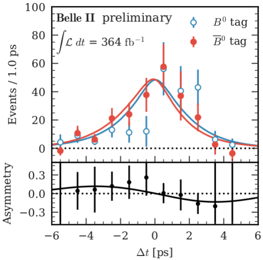


$$\mathcal{B} = \left(29.0^{+2.3}_{-2.2} \pm 3.1\right) \times 10^{-6}$$

$$\mathbf{f_L} = 0.921^{+0.024+0.017}_{-0.022-0.015}$$

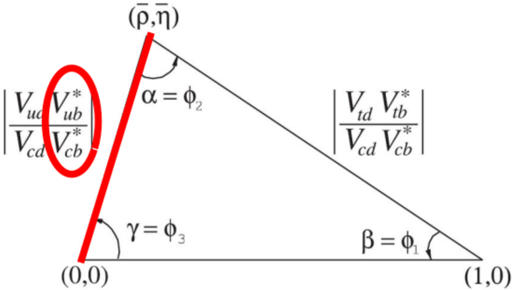
$$\mathcal{S} = (-0.26 \pm 0.19 \pm 0.08)$$

$$\mathcal{C} = -0.02 \pm 0.12^{+0.06}_{-0.05}$$



$\phi_2(\mathbf{B} \to \rho\rho)$	
WA	$\left(91.5^{+4.5}_{-5.4}\right)^\circ$
WA + New Results	$\left(92.6^{+4.5}_{-4.8}\right)^\circ$

- 6% improvement by Belle II results!
- Consistent with previous measurements
- Paper in preparation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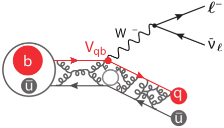
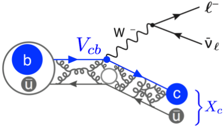
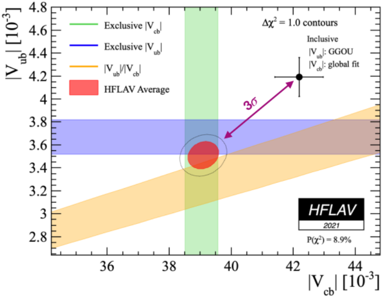
$\left|\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right|$
$\alpha = \phi_2$
$\left|\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}\right|$
$\gamma = \phi_3$
$\beta = \phi_1$
(0,0)
(1,0)

DETERMINATION OF $|V_{ub}|$ & $|V_{cb}|$

- $|V_{ub}|$ and $|V_{cb}|$ are important to constrain CKM unitarity
- Precisely measured via semileptonic B decays.
- Significant tension between inclusive & exclusive determinations



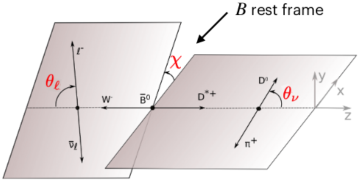




Exclusive $\lvert V_{xb}\rvert$	**Inclusive** $\lvert V_{xb}\rvert$
Exclusive $\lvert V_{ub}\rvert$: $\bar{B} \to \pi\ell\bar{\nu}_\ell$	**Inclusive** $\lvert V_{ub}\rvert$: $\bar{B} \to X_u\ell\bar{\nu}_\ell$
Exclusive $\lvert V_{cb}\rvert$: $\bar{B} \to D\ell\bar{\nu}_\ell$, $\bar{B} \to D^*\ell\bar{\nu}_\ell$	**Inclusive** $\lvert V_{cb}\rvert$: $\bar{B} \to X_c\ell\bar{\nu}_\ell$
$\mathcal{B} \propto \lvert V_{qb}\rvert^2 f^2$ $f \to$ *Form Factors*	$\mathcal{B} = \lvert V_{qb}\rvert^2 \left[\Gamma(b \to q\ell\bar{\nu}_\ell) + \frac{1}{m_{c,b}} + \alpha_s + \ldots\right]$ Heavy Quark Expansion

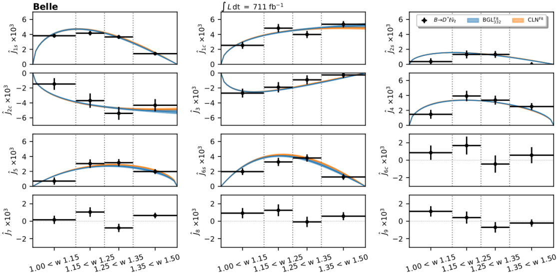
$|V_{cb}|$ from $\bar{B} \to D^* \ell \bar{\nu}_\ell$

- $|V_{cb}|$ from angular analysis of $B \to D^* \ell \bar{\nu}_\ell$
- Full Belle dataset ($711\ \mathrm{fb}^{-1}$) with hadronic B tagging
- Reconstruct both charged and neutral B
  - $\bar{B}^0 \to D^{*+} \ell \bar{\nu}_\ell,\ D^{*+} \to D^0 \pi^+ / D^+ \pi^0$
  - $B^- \to D^{*0} \ell \bar{\nu}_\ell,\ D^{*0} \to D^0 \pi^0$



- Four-dimensional differential decay rate for $\bar{B} \to D^* \ell \bar{\nu}_\ell$ can be expressed in terms of 12 functions
- Angular coefficients obtained from data in bins of the hadronic recoil parameter $w = \frac{m_B^2 + m_{D^*}^2 - q^2}{2 m_B m_{D^*}}$
- Measure 12 angular coefficients J_i in four bins of w
- Determine signal yields by fitting the mass of undetected neutrinos in the event: $M^2_{\text{miss}} = \left(p_{e^+} + p_{e^-} - p_{B_{B_{tag}}} - p_{D^*} - p_\ell \right)^2$

$|V_{cb}|$ from $\bar{B} \to D^* \ell \bar{\nu}_\ell$



Phys.Rev.Lett.133(2024)131801

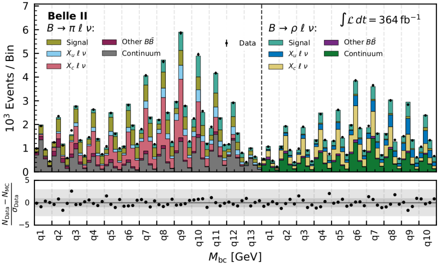
$$|V_{cb}|_{\mathrm{BGL}} = (41.0 \pm 0.3 \pm 0.4 \pm 0.5) \times 10^{-3}$$

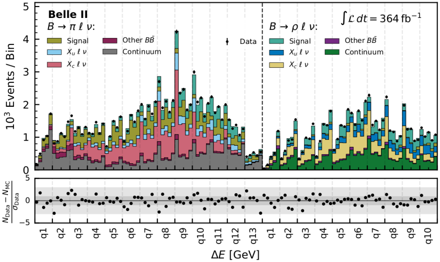
$$|V_{cb}|_{\mathrm{CLN}} = (40.9 \pm 0.3 \pm 0.4 \pm 0.4) \times 10^{-3}$$

- **Agrees with the latest and most precise determinations of inclusive $|V_{cb}|$**
- Results in agreement with fits to 1D partial rates on the same data set PhysRevD.108.012002 as well as on Belle II data arXiv:2310.01170v2

$|V_{ub}|$ from $B^0 \to \pi^- \ell^+ \nu_\ell$ & $B^+ \to \rho^0 \ell^+ \nu_\ell$

- The rates of $b \to u$ decays is proportional to $|V_{ub}|$
- Full Belle II Run1 dataset of 364 fb-1, untagged
- Extract signal yields from fit to binned MC templates
  - 2 kinematic variables in bins of q^2 simultaneously for $\pi\ell\nu$ and $\rho\ell\nu$
  - $q^2 = (P_B - P_{\pi/\rho})^2$
- Background suppressed using BDTs
- Total branching ratio is the sum of all the partial ΔB_i in each q^2 bin



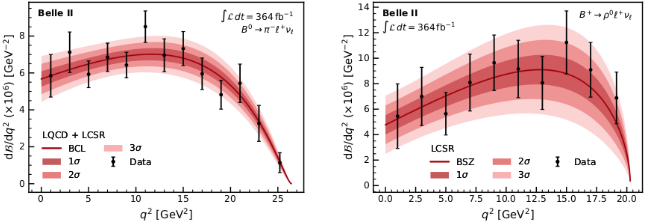


$|V_{ub}|$ from $B^0 \to \pi^- \ell^+ \nu_\ell$ & $B^+ \to \rho^0 \ell^+ \nu_\ell$

arxiv:2407.17403 [PRD]

$$\mathcal{B}\left(B^0 \to \pi^- \ell^+ \nu_\ell\right) = (1.516 \pm 0.042(\text{ stat }) \pm 0.059(\text{ syst })) \times 10^{-4}$$
$$\mathcal{B}\left(B^+ \to \rho^0 \ell^+ \nu_\ell\right) = (1.625 \pm 0.079(\text{ stat }) \pm 0.180(\text{ syst })) \times 10^{-4}$$

Consistent with PDG



$B^0 \to \pi^- \ell^+ \nu_\ell : |V_{ub}| = (\mathbf{3.73} \pm \mathbf{0.07}(\text{stat}) \pm \mathbf{0.07}(\text{syst}) \pm \mathbf{0.16}(\text{theo})) \times 10^{-3}$ LQCD+LCSR constraints

$B^+ \to \rho^0 \ell^+ \nu_\ell : |V_{ub}| = (\mathbf{3.19} \pm \mathbf{0.12}(\text{stat}) \pm \mathbf{0.17}(\text{syst}) \pm \mathbf{0.26}(\text{theo})) \times 10^{-3}$ LCSR constraints

- Consistent with WA
- Comparable precision with Belle/Babar

SUMMARY

- Belle II has already recorded a total of 531 fb^{-1} of data
- Precise measurements of CKM angles and sides are crucial for increasing the constraining power of the Unitarity Triangle fit.
- The new GNN-based flavor tagger has achieved an 18% improvement in effective tagging efficiency
- ϕ_2: $B \to \pi^0\pi^0$, $B^0 \to \rho^+\rho^-$
  - New results with improved precision, the first ϕ_2 extraction with improved precision
- ϕ_3: First combined Belle and Belle II analysis, achieving improved sensitivity
- Belle and Belle II continue to produce updated and improved measurements of $|V_{cb}|$ and $|V_{ub}|$

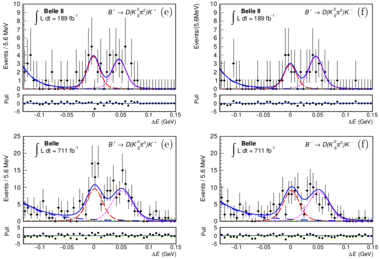
Thank You!

BACKUP

$\phi_3 : B^\pm \to D_{CP} K^\pm$ in Belle + Belle II Data

Observables: Direct CPV in $\mathcal{B}$ Ratio

- $\mathcal{A}_{CP\pm} \equiv \dfrac{\mathcal{B}(B^-\to D_{CP\pm}K^-)-\mathcal{B}(B^+\to D_{CP\pm}K^+)}{\mathcal{B}(B^-\to D_{CP\pm}K^-)+\mathcal{B}(B^+\to D_{CP\pm}K^+)}$
- $\mathcal{R}_{CP\pm} \equiv \dfrac{\mathcal{B}\big(B^-\to D_{CP\pm}K^-\big)+\mathcal{B}\big(B^+\to D_{CP\pm}K^+\big)}{\big(\mathcal{B}(B^-\to D_{\text{flav}}\,K^-)+\mathcal{B}\big(B^+\to \bar{D}_{\text{flav}}\,K^+\big)\big)/2}$
- D_{CP+}: CP-even decay ($D \to K^+K^-$)
- D_{CP-}: CP-odd decay ($D \to K_s^0\pi^0$)
- D_{flav}: Flavor-specific decay ($D \to K^\pm\pi^\mp$)



$$\mathcal{R}_{CP\pm} = 1 + r_B^2 \pm 2 r_B \cos\delta_B \cos\phi_3$$

$$\mathcal{A}_{CP\pm} = \pm 2 r_B \sin\delta_B \sin\phi_3 / \mathcal{R}_{CP\pm}.$$

$$\mathcal{R}_{CP+} = 1.164 \pm 0.081 \pm 0.036,$$

$$\mathcal{R}_{CP-} = 1.151 \pm 0.074 \pm 0.019,$$

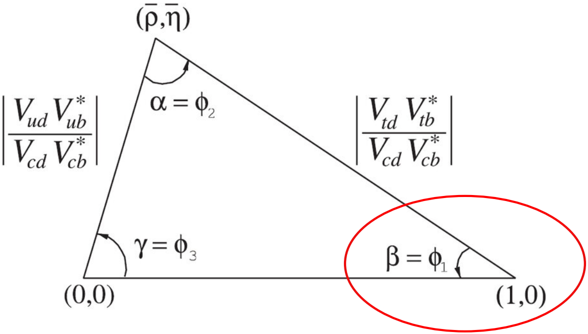
$$\mathcal{A}_{CP+} = (+12.5 \pm 5.8 \pm 1.4)\%,$$

$$\mathcal{A}_{CP-} = (-16.7 \pm 5.7 \pm 0.6)\%,$$

3σ evidence for $A_{CP-} \neq \mathcal{A}_{CP+}$

JHEP05(2024)212

GLW method


$(\bar{\rho},\bar{\eta})$
$\alpha = \phi_2$
$\left|\frac{V_{ud} V_{ub}^*}{V_{cd} V_{cb}^*}\right|$
$\left|\frac{V_{td} V_{tb}^*}{V_{cd} V_{cb}^*}\right|$
$\gamma = \phi_3$
$\beta = \phi_1$
(0,0)
(1,0)

ANGLE $\phi_1(\beta)$

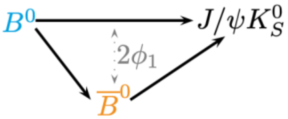
Time-dependent CPV

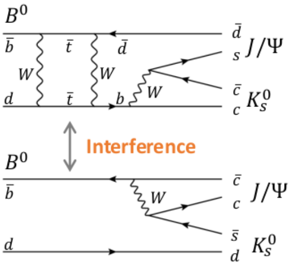
- Oscillation-induced CPV as a function of Δt
- Boosted CMS to measure Δt from decay length

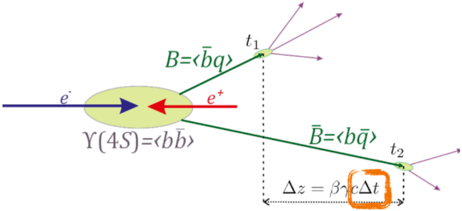
$$\mathbf{A_{CP}^{B\to f}(\Delta t)} \equiv \frac{\Gamma\left(B^0(\Delta t)\to f\right) - \Gamma\left(\bar{B}^0(\Delta t)\to f\right)}{\Gamma\left(B^0(\Delta t)\to f\right) + \Gamma\left(\bar{B}^0(\Delta t)\to f\right)}$$

$$= \mathbf{S}\cdot\sin\left(\Delta m_d \Delta t\right) - \mathbf{C}\cdot\cos\left(\Delta m_d \Delta t\right)$$

S = $|\sin(2\phi_1)|$ = Mixing induced CPV
C = Direct CPV





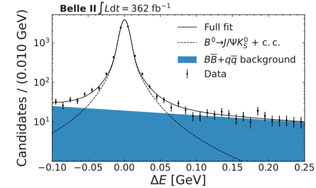


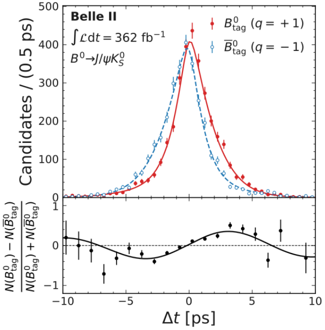
$\phi_1 : B^0 \to J/\psi K_S^0$

PhysRevD.110.012001

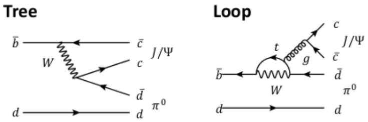
- $b \to c\bar{c}s$ transition
- Uses the GFlat flavor-tagging algorithm
- Yield extraction fit to ΔE
- Fit background-free Δt for parameters of interest
- Improved statistical uncertainty 8% (S) and 7% (C) compared to category-based FBDT flavor tagger

$$S = 0.724 \pm 0.035 \pm 0.009$$
$$\to \phi_1 = (23.2 \pm 1.5 \pm 0.6)^\circ$$
$$\mathrm{C} = -0.035 \pm 0.026 \pm 0.029$$

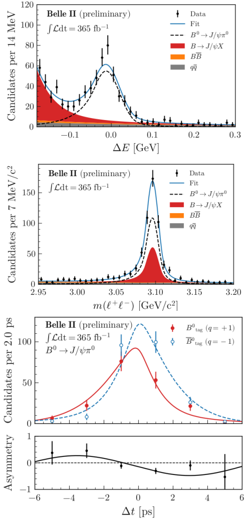




ϕ_1 : $B^0 \to J/\psi\pi^0$



arxiv:2410.08622[PRD]



- CKM & color-suppressed tree-level $b \to c\bar{c}d$
- Constrain the loop contributions in $B^0 \to J/\psi K^0$ ($b \to c\bar{c}s$) to determine ϕ_1
- Fit ΔE & $m(ll)$ for background subtraction and extract yields
- Fit Δt to extract CPV parameters
- 1^{st} 5 σ observation TDCPV in this mode

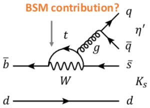
$$\mathbf{BF} = (2.00 \pm 0.12 \pm 0.10) \times 10^{-5}$$

$$\mathbf{S_{CP}} = -0.88 \pm 0.17 \pm 0.03$$

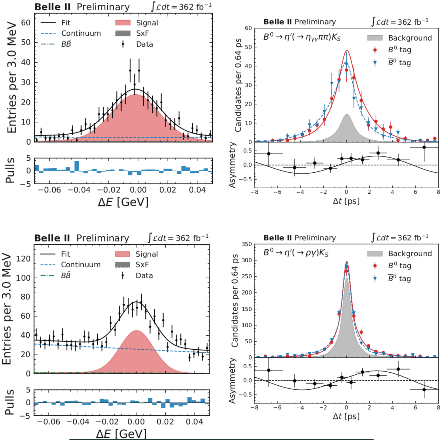
$$\mathbf{C_{CP}} = 0.13 \pm 0.12 \pm 0.03$$

- Most precise and comparable with previous measurements

$\phi_1 : B^0 \to \eta' K_S$



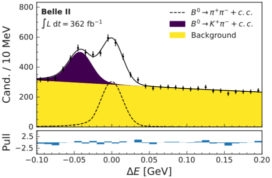
- Dominated by the Loop process: BSM could shift S & C
- Relatively large BF and limited contribution from tree amplitudes compared to other $b \to sq\bar{q}$
- $\eta' \to \eta(\gamma\gamma)\pi\pi$ & $\eta' \to \rho(\pi\pi)\gamma$
- SM prediction:
  - $|sin(2\phi_1) - S_{\eta' K_S}| = 0.01 \pm 0.01$
  - $C_{\eta' K_S} = 0$
- Fits to ΔE, $M_{\rm bc}$, C_{BDT} & Δt
- Agreement with WA and compatible with Belle/Babar precision

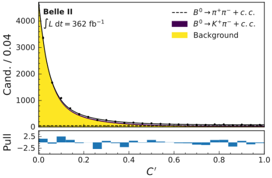


	Measured	WA
$S_{\eta' K^0}$	$0.67 \pm 0.10 \pm 0.04$	0.64 ± 0.05
$C_{\eta' K^0}$	$-0.19 \pm 0.08 \pm 0.03$	-0.08 ± 0.04

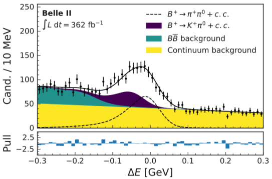
arxiv:2402.03713[PRD]

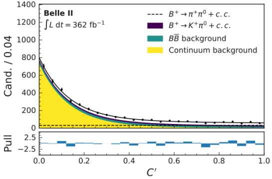
$\phi_2 : B^0 \to \pi^+\pi^-$ and $B^+ \to \pi^+\pi^0$





$B^0 \to \pi^+\pi^-$: BR $= (5.83 \pm 0.22 \pm 0.17)10^{-6}$





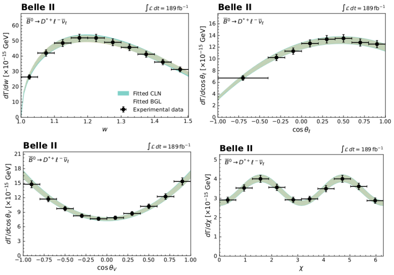
$B^+ \to \pi^+\pi^0$: BR $= (5.10 \pm 0.29 \pm 0.27)10^{-6}$

$A_{CP} = -0.081 \pm 0.054 \pm 0.008$

PhysRevD.109.012001

- Good agreement with previous measurements
- Sensitivity is comparable with Belle using only half of Belle's data!

$|V_{cb}|$ from $\bar{B} \to D^* \ell \bar{\nu}_\ell$



- Using 189 fb^{-1} of Belle II data
- Partial decay rates are reported as a function of the recoil parameter and three decay angles

$$\mathcal{B}\left(\bar{B}^0 \to D^{*+} e^- \bar{\nu}_e\right) = (4.917 \pm 0.032 \pm 0.216)\%,$$
$$\mathcal{B}\left(\bar{B}^0 \to D^{*+} \mu^- \bar{\nu}_\mu\right) = (4.926 \pm 0.032 \pm 0.231)\%,$$
$$\mathcal{B}\left(\bar{B}^0 \to D^{*+} \ell^- \bar{\nu}_\ell\right) = (4.922 \pm 0.023 \pm 0.220)\%,$$

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

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

- Signal extraction with fit to $\cos\theta_{BY}$ and ΔM in bins of $w, \cos\theta_\ell, \cos\theta_v$ and χ
- Good agreement with the world average of the exclusive and inclusive determinations
- Agrees with the recent Belle measurement PhysRevD.108.012002