CPV and CKM at Belle II: status and prospects

Michele Mantovano (University and INFN Trieste)
on behalf of the Belle II Collaboration

WIFAI 2024
Bologna, Nov 12, 2024

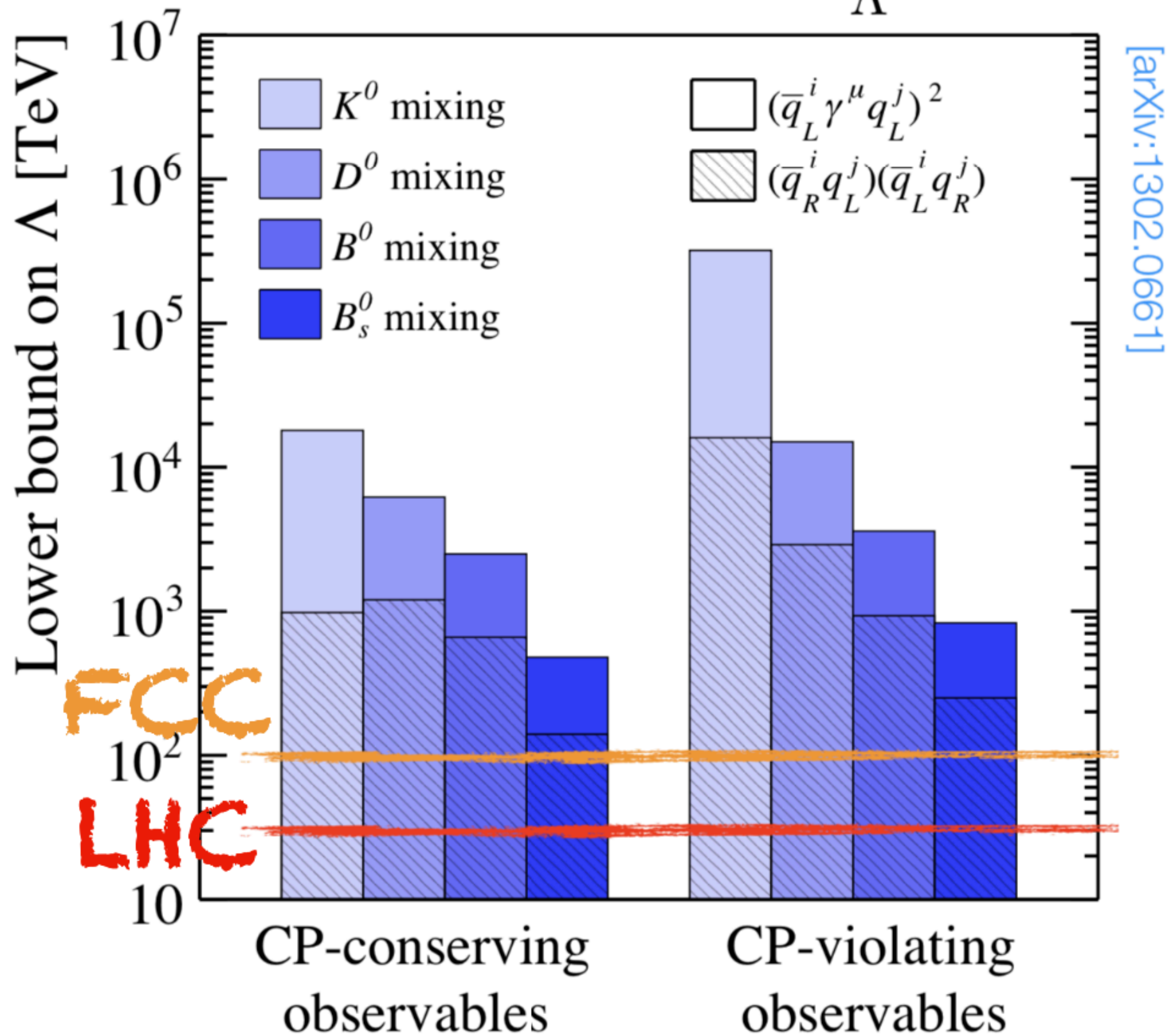
Probing the next scale

Flavor physics to access higher scales than those directly reachable at the current or future colliders.

Systematic approach to probe many redundant observables and look for differences respect to the SM predictions.

CKM paradigm remarkably successful so far, but deviations still allowed in most of the suppressed processes.

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda^2}\mathcal{O}_{\Delta F=2}$$



Name of the game is precision.

Boosting the reach

Energy-asymmetric e^+e^-collisions at the $\Upsilon(4S)$ from SuperKEKB.

Unprecedented luminosity $4.7 \cdot 10^{34}$cm^{-2}s^{-1}.

From Belle: structure, magnets,

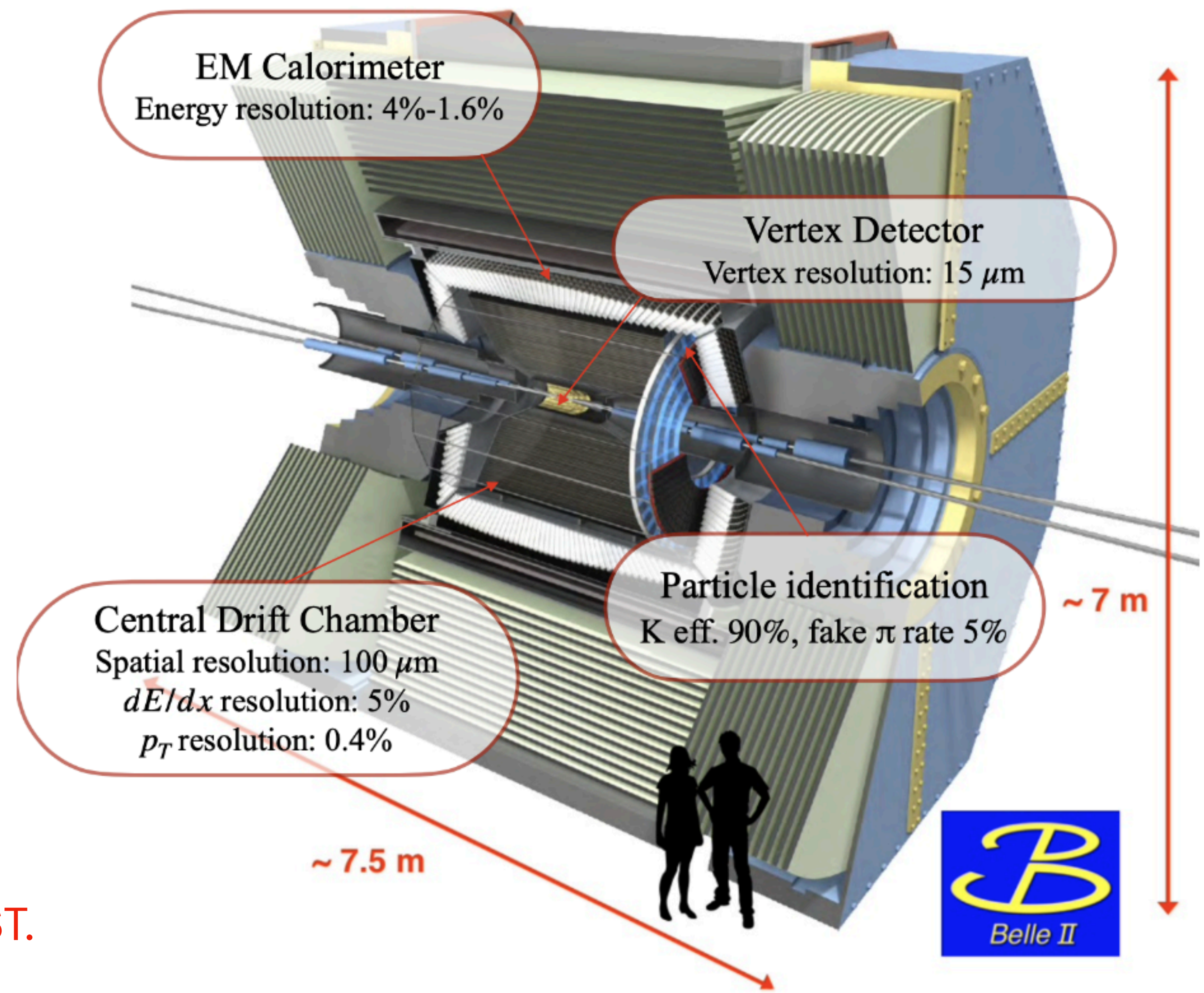
calorimeter crystals, K_L & μ detector.

Excellent vertexing resolution
and tracking efficiency.
Good PID and neutrals.

Run 1: collected $387 \cdot 10^6$ $B\bar{B}$ pairs.

Starting Run 2 after
improving vertex detector.

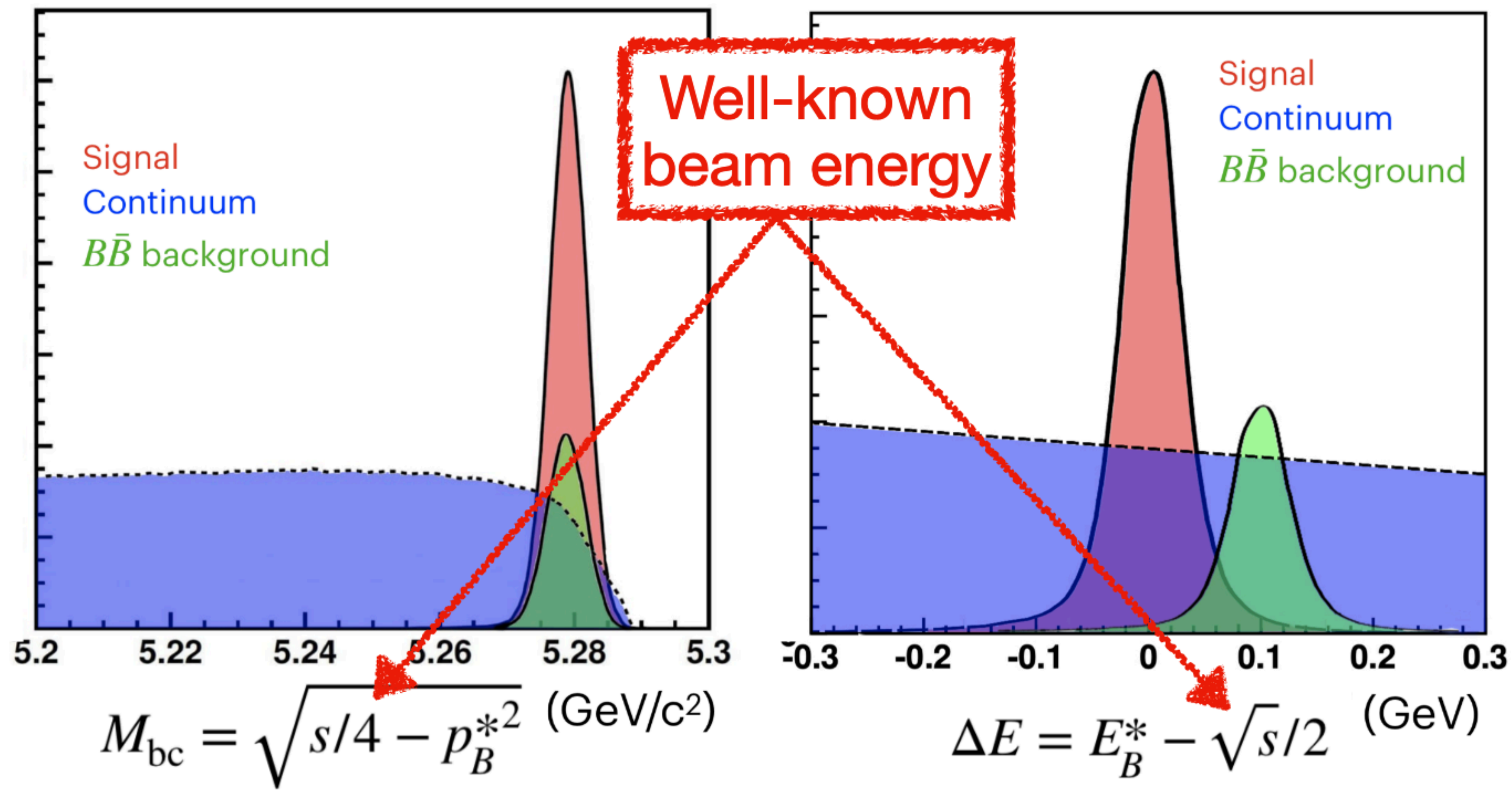
First Run 2 collision: 20 Feb 2024, 22:12 JST.



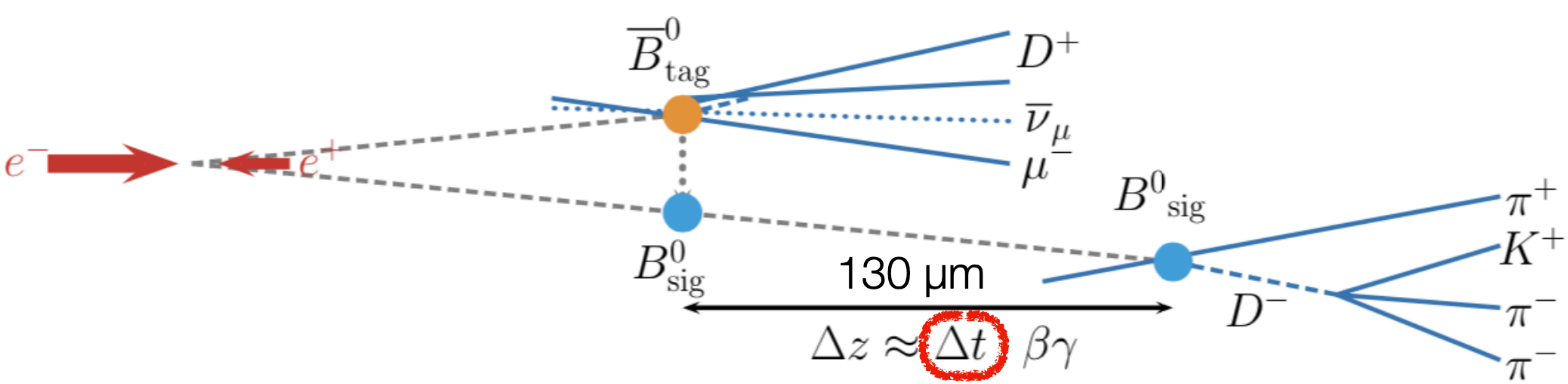
B-factory basics

Low-background of 30 (now)—600 (design) $B\overline{B}$ per second.

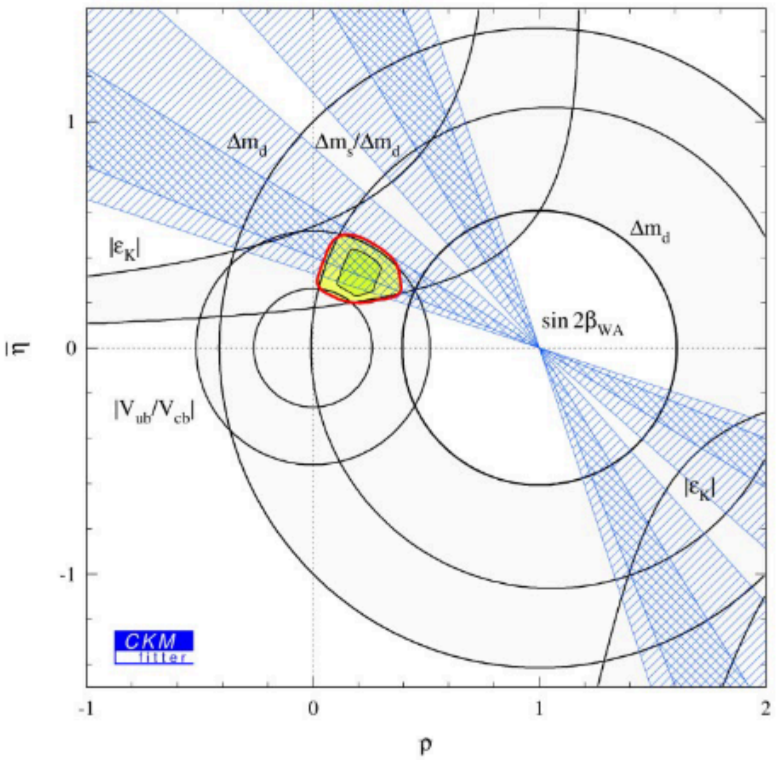
Threshold B production from point-like colliding particles, $e^+e^- \to \Upsilon(4S) \to B\overline{B}$. Kinematic well constrained.



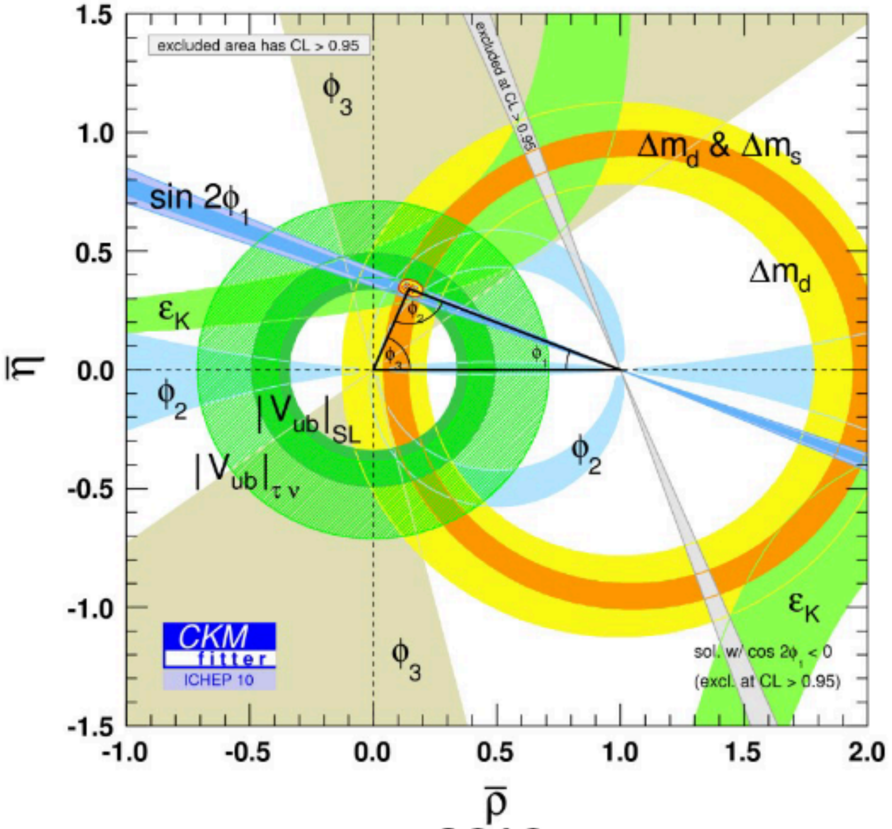
The asymmetric collision gives the boost to measure the displacement and tag the flavor.



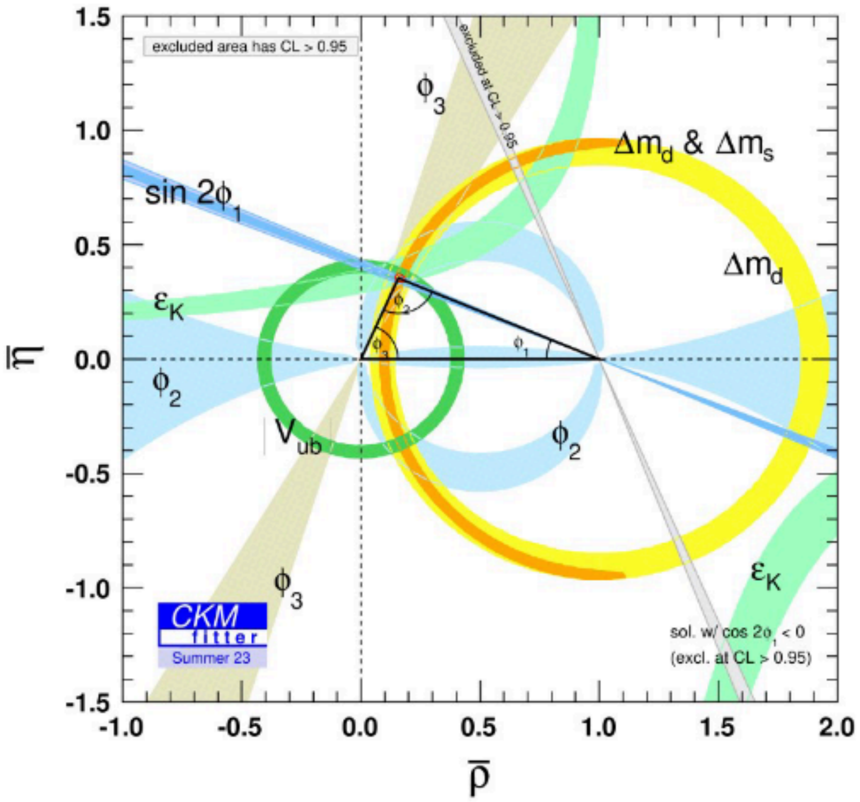
CKM angles and CP violation



2001



2010



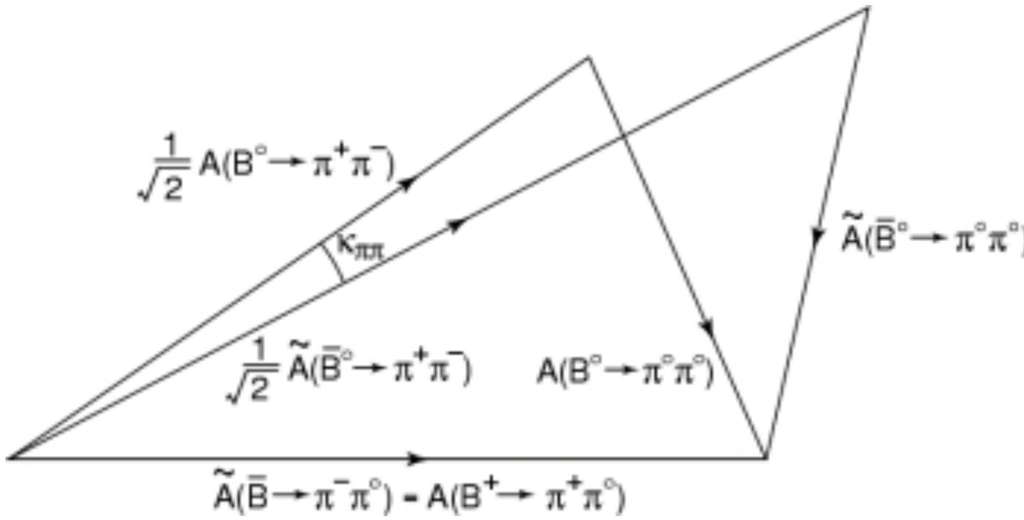
2023

$B^0 \to \pi^0\pi^0$ towards ϕ_2

$\phi_2 = arg\left[-V_{td}V_{tb}^*/V_{ud}V_{ub}^*\right]$ less precisely known angle: limit global testing power of CKM fits.

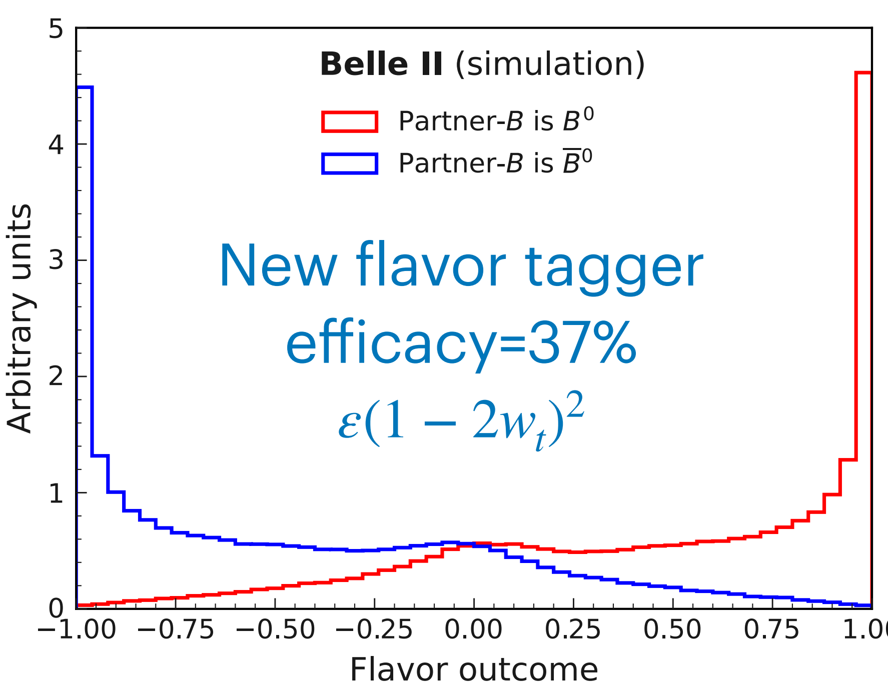
Determine from $B \to \rho\rho$ and $B \to \pi\pi$ isospin analyses.

Unique Belle II capability to study in consistent way all $B \to \pi\pi$.



Challenges:

- rare, small *BF* (10^{-6}),
- only photons in the final state — dominated by signal-like background,
- A_{CP}: flavor from partner B (flavor tagger).



Optimize photon selection and light-quark bkg suppression, extract signal by fitting kinematic, event-shape, and tagging observables, validate on $B^+ \to K^+\pi^0$.

$B^0 \to \pi^0\pi^0$ towards ϕ_2

Extract signal from fit to ΔE, M_{bc}, C, w_t.

Improvements wrt early Belle II:

– doubled sample size,
– improved suppression of backgrounds,
– better flavor tagging algorithms,
– improved systematic uncertainties.

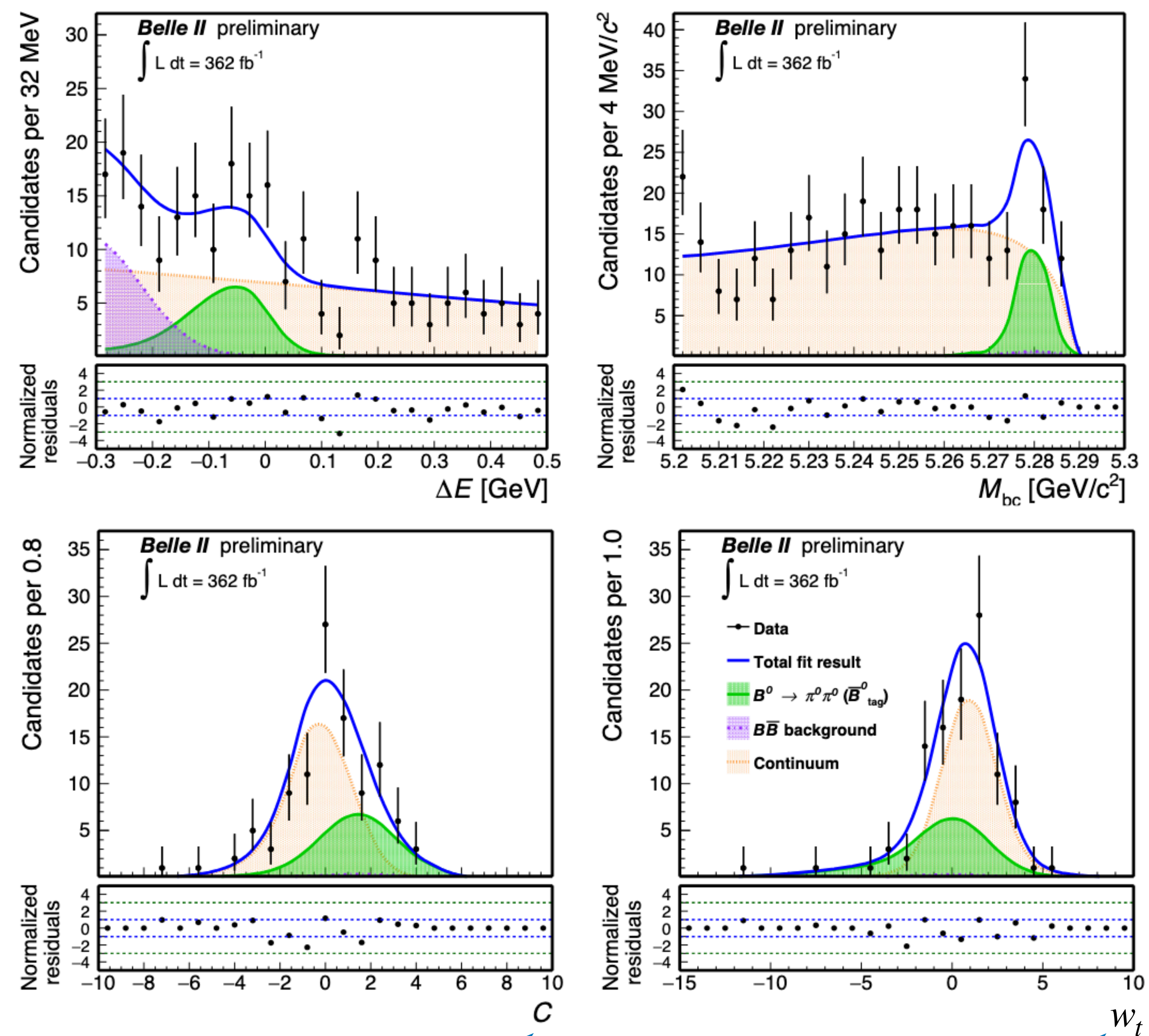
Previous Belle II results (PRD.107.112009)

$$\mathscr{B} = (1.38 \pm 0.27 \pm 0.22) \times 10^{-6}$$
$$A_{CP} = 0.14 \pm 0.46 \pm 0.07$$

New Belle II results (paper in preparation)

$$\mathscr{B} = (1.26^{+0.20}_{-0.19} \pm 0.11) \times 10^{-6}$$
$$A_{CP} = 0.06 \pm 0.30 \pm 0.06$$

126 ± 20 signal events



Combination of event shape variables

Modified probability of wrongly assigned flavor

World-best $\mathscr{B}$ determination. A_{CP} on par with world best in spite of smaller sample.

$B^0 \to \rho^+\rho^-$ towards ϕ_2

paper in preparation

Reconstruct $B^0 \to \rho^+\rho^-$, with $\rho^\pm \to \pi^\pm\pi^0$ and $\pi^0 \to \gamma\gamma$.

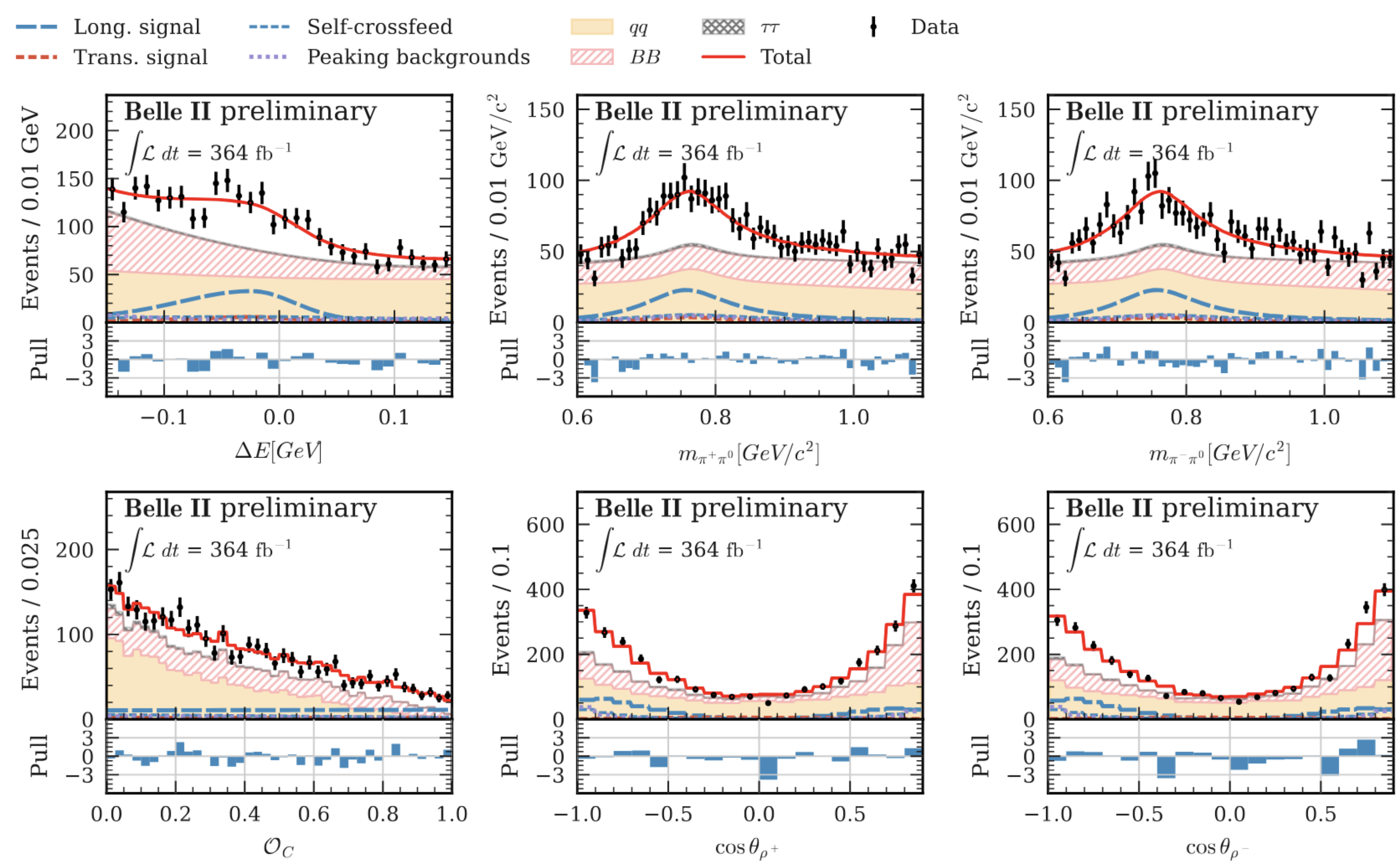
$$\mathscr{A}_{CP}(\Delta t) = \frac{\Gamma(\overline{B}^0 \to f_{CP}) - \Gamma(B^0 \to f_{CP})}{\Gamma(\overline{B}^0 \to f_{CP}) + \Gamma(B^0 \to f_{CP})}(\Delta t) = S\sin(\Delta m \Delta t) - C\cos(\Delta m \Delta t)$$

$$S = \sqrt{1 - C^2}\sin(2\phi_2 + \Delta\phi_2)$$

Main offenders:

— background modelling
— Data-MC mis-modelling

Signal extraction via 6 observables ΔE, $m_{\pi^\pm\pi^0}$, $\cos\theta_{\rho^\pm}$ and τ_C.



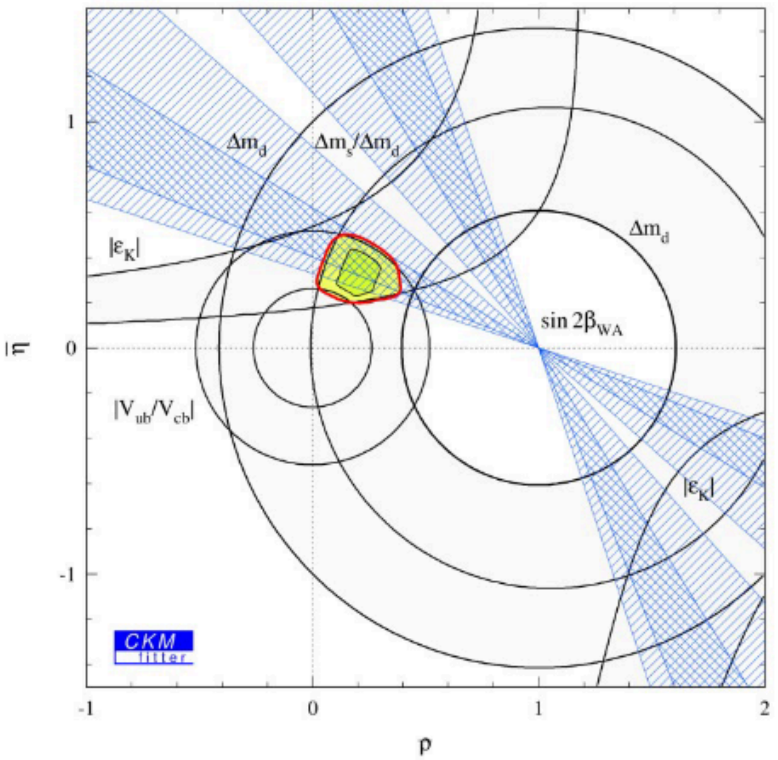
$$S = -0.26 \pm 0.19 \pm 0.08$$

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

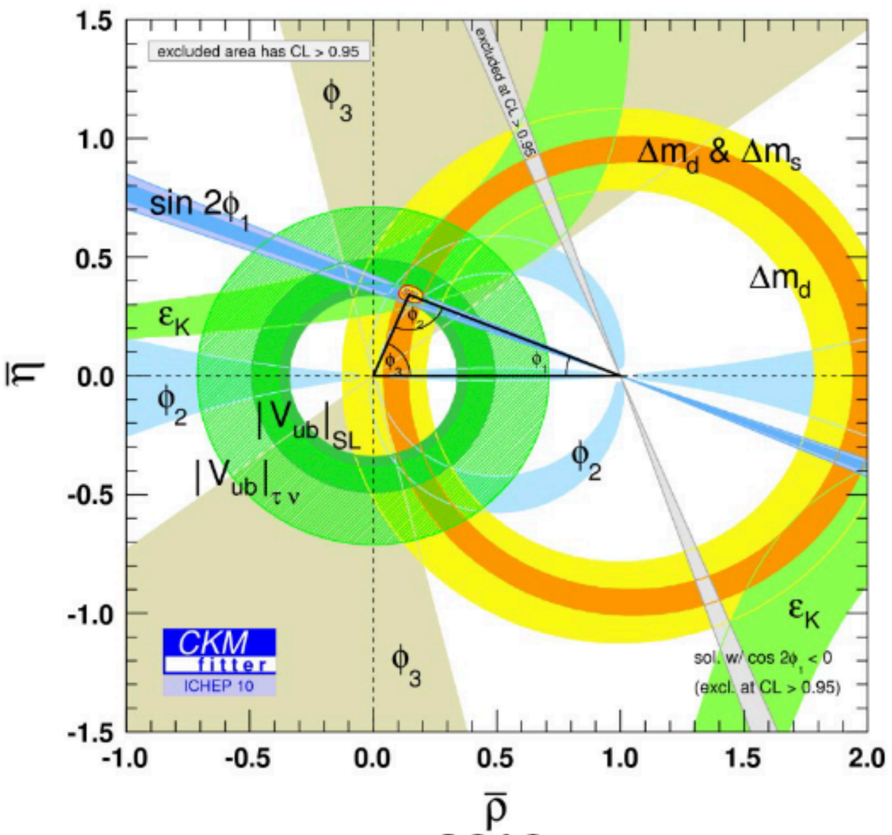
$$\phi_2 = (92.6^{+4.5}_{-4.8})^\circ$$

Consistent with the SM predictions.

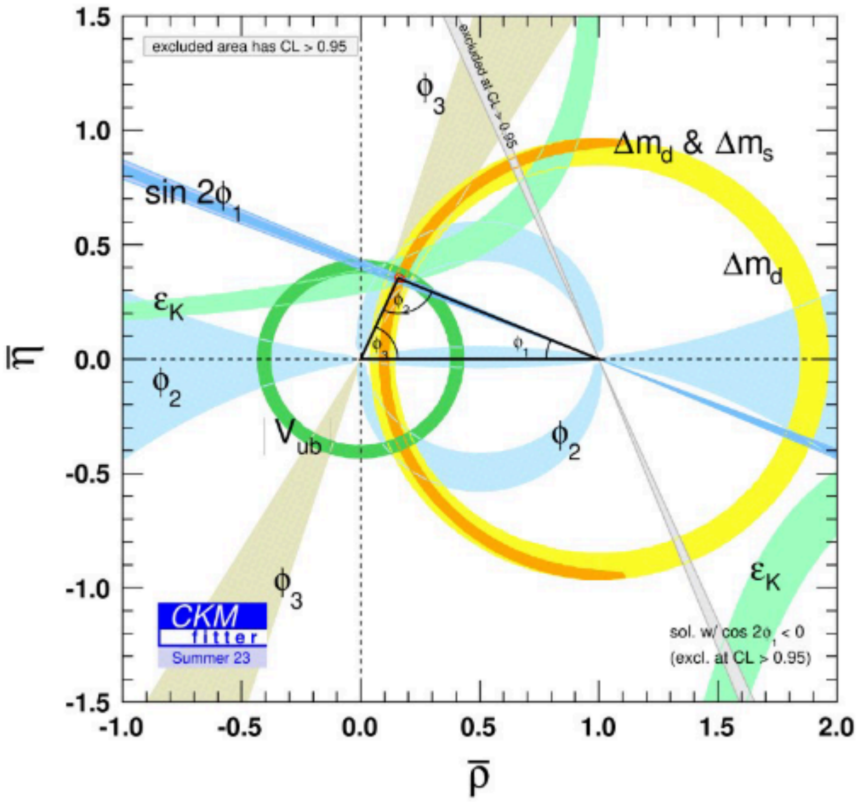
CKM couplings



2001



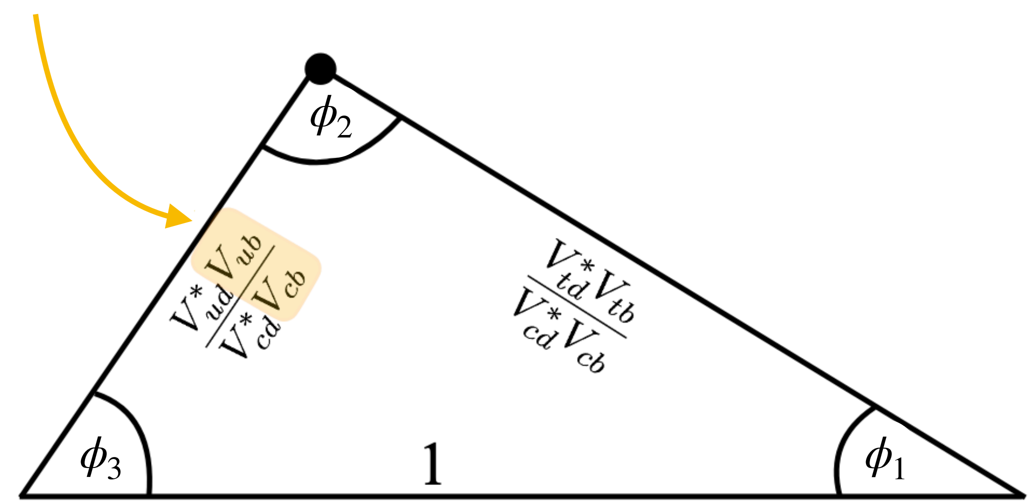
2010



2023

$|V_{ub}|$ and $|V_{cb}|$

- SL B decays ideal to extract CKM matrix elements $|V_{cb}|$ and $|V_{ub}|$.
- Important inputs to predictions of SM rates for ultra-rare decays.
- Significant tension between inclusive and exclusive determinations.



Exclusive

$|V_{ub}|$	$|V_{cb}|$
$B \to \pi, \rho \ell \nu$	$B \to D^{(*)} \ell \nu$

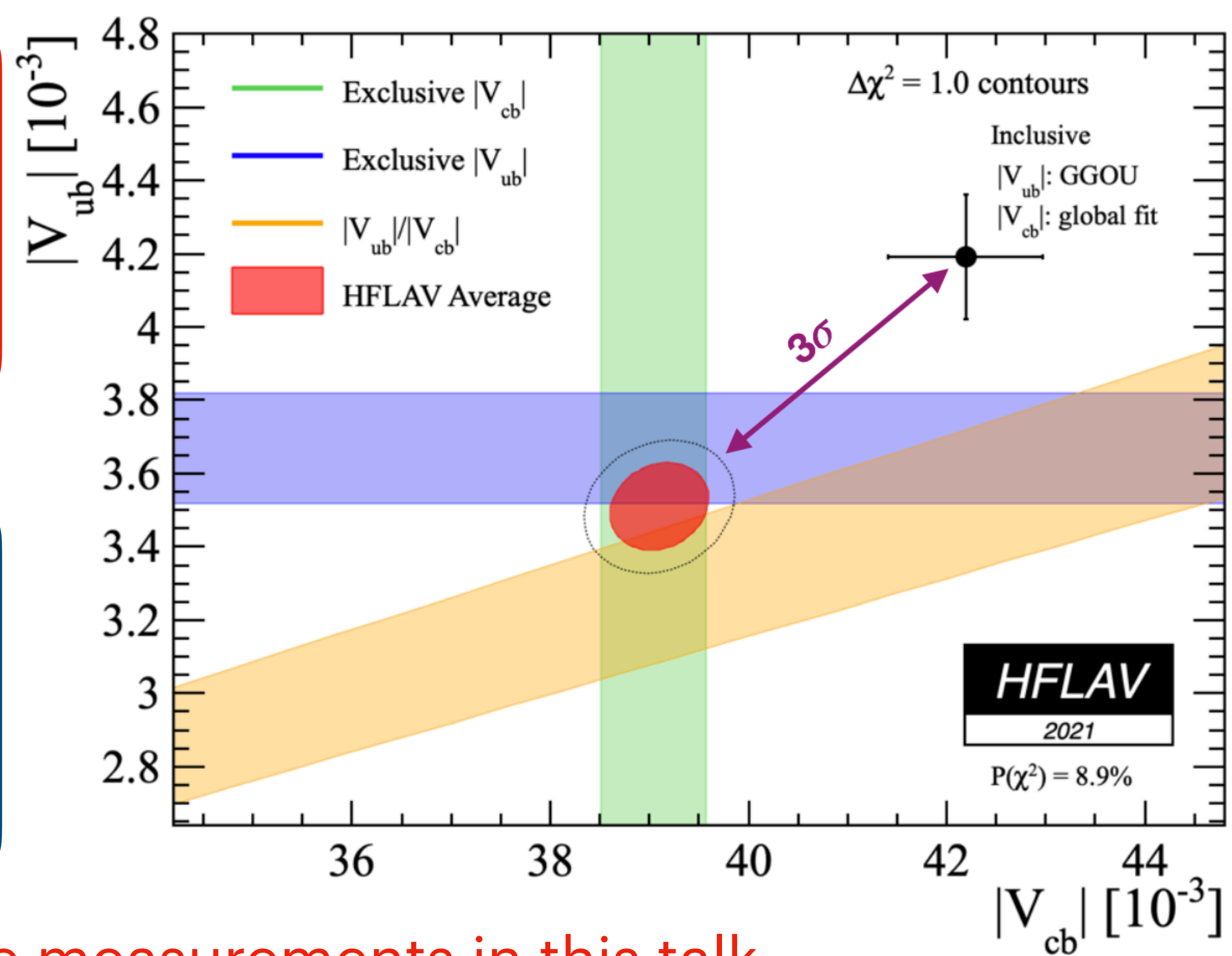
$\mathscr{B} \propto |V_{xb}|^2 FF^2$ form factors

Inclusive

$|V_{ub}|$	$|V_{cb}|$
$B \to X_u \ell \nu$	$B \to X_c \ell \nu$

Heavy quark expansion

$$\mathscr{B} = |V_{xb}|^2 \left[\Gamma(b \to q \ell \nu_\ell) + 1/m_{c,b} + \alpha_s + \ldots \right]$$



Focus only on the exclusive measurements in this talk.

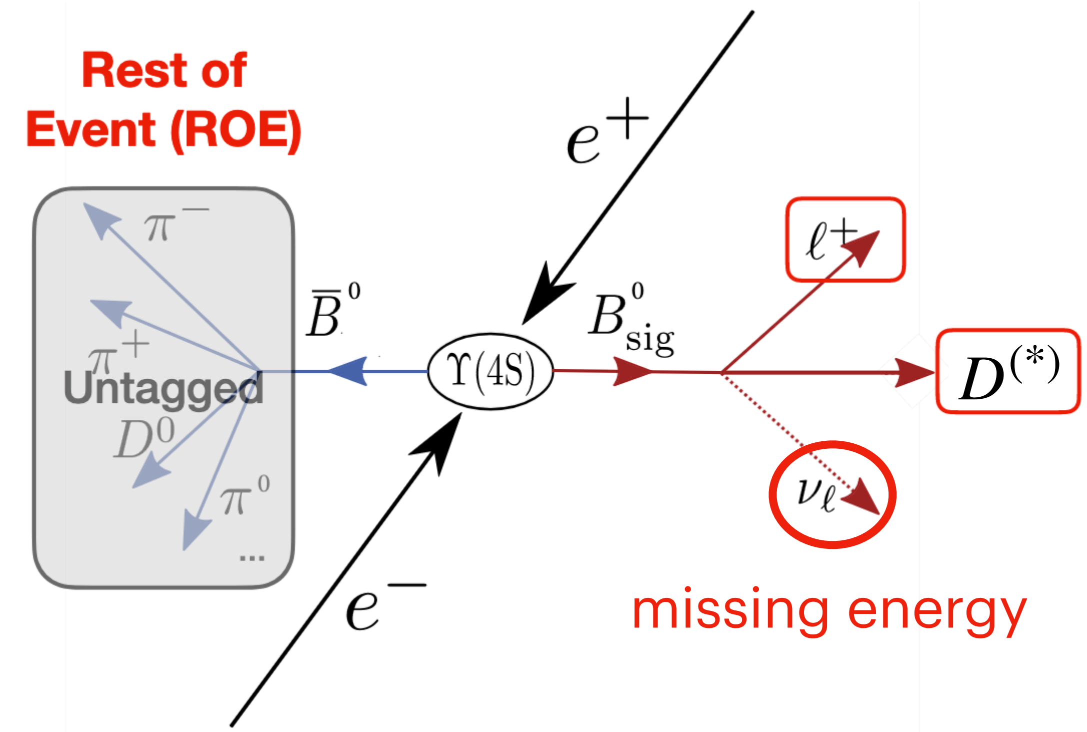
Dealing with missing energy

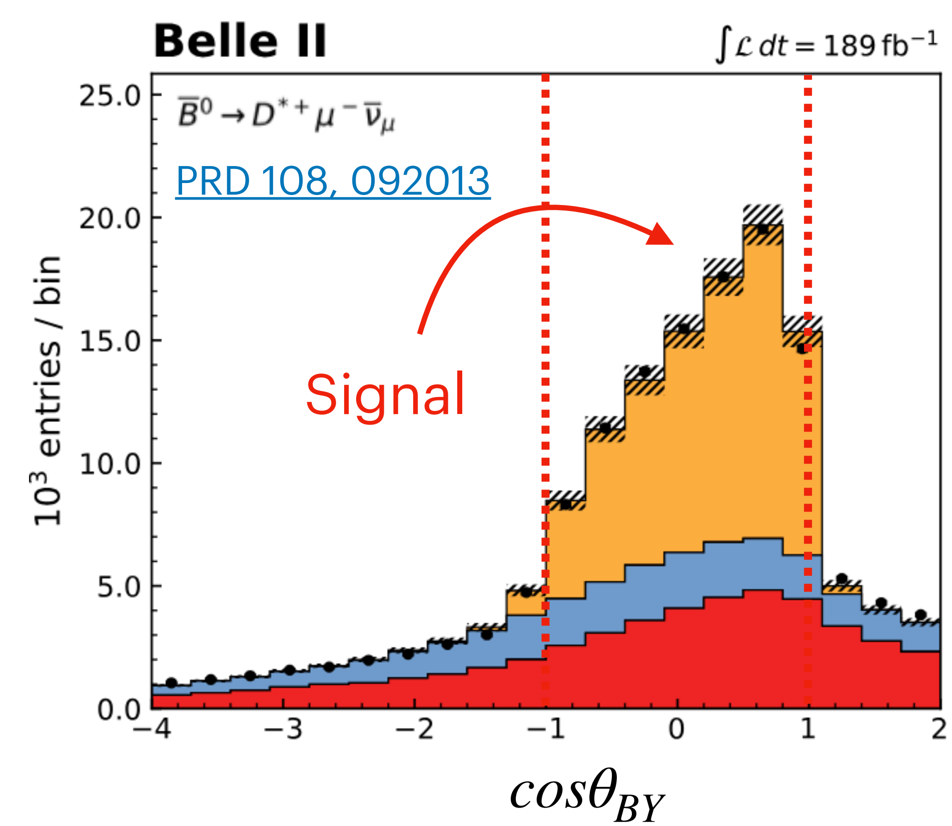
All SL analyses covered here are UNTAGGED:

- No systematic related to B tagging efficiency, important for BR and $|V_{xb}|$.
- High efficiency compensate for low resolution of approximated B kinematics.
- No discriminating B peak for signal.
  - Leverage $M(D)$ and $\Delta M = M(D^*) - M(D)$ narrow peaks.
  - M_{bc} and ΔE.
  - use available kinematic constraints:

$$cos\theta_{BY} = \frac{2E_B^* E_Y^* - m_B^2 - m_Y^2}{2|p_B^*||p_Y^*|}$$

$Y = D\ell$ system



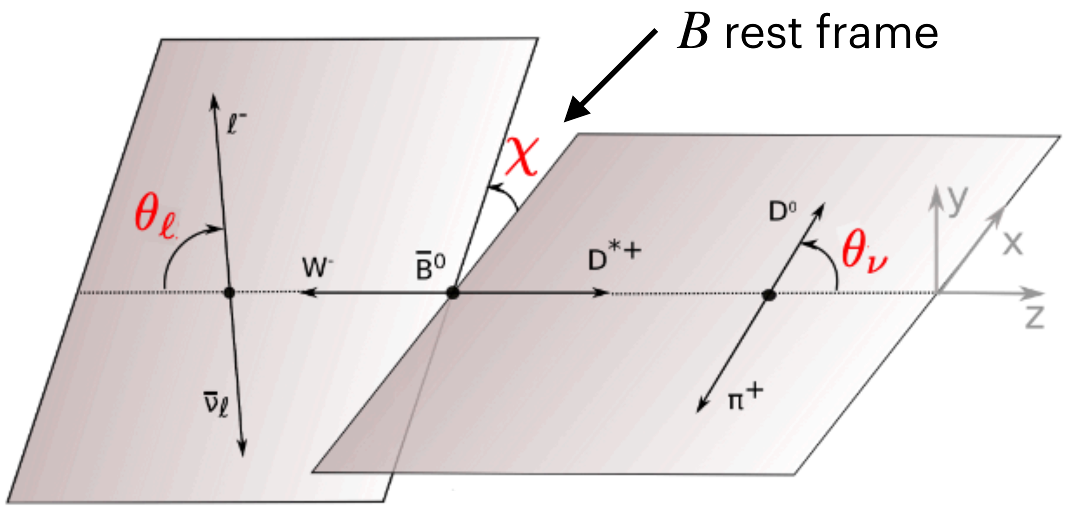


$|V_{cb}|$ from $B^0 \to D^{*+}\ell^-\nu$

First analysis on $|V_{cb}|$ from Belle II.

Rich phenomenology due to different decay amplitudes encoded in angular distributions.

Reconstruct $B^0 \to D^{*+}\ell^-\nu$, with $D^{*+} \to D^0[\to K^-\pi^+]\pi^+_{soft}$.

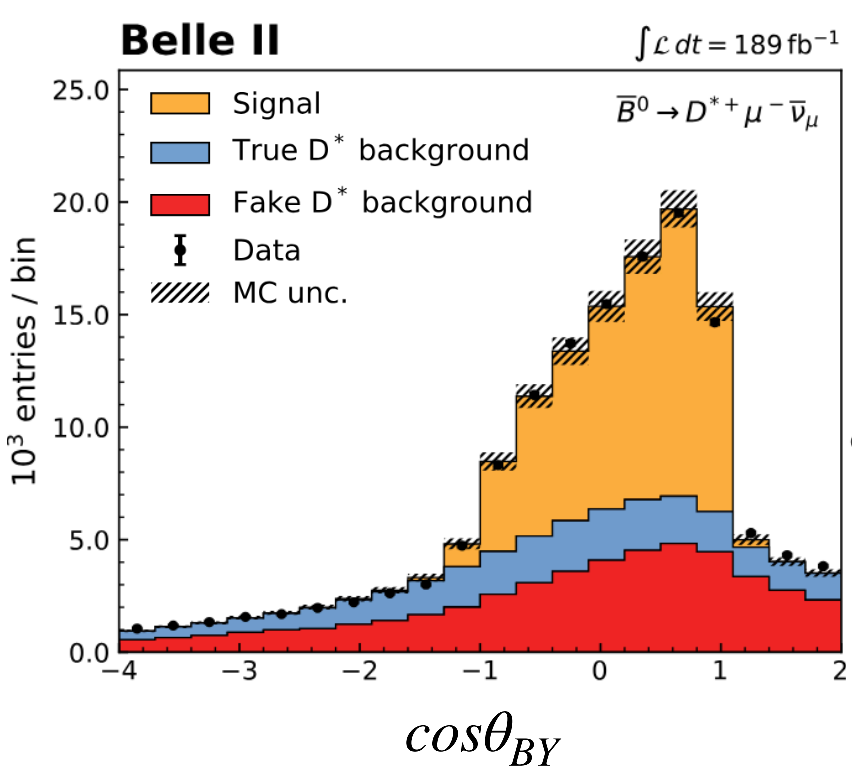


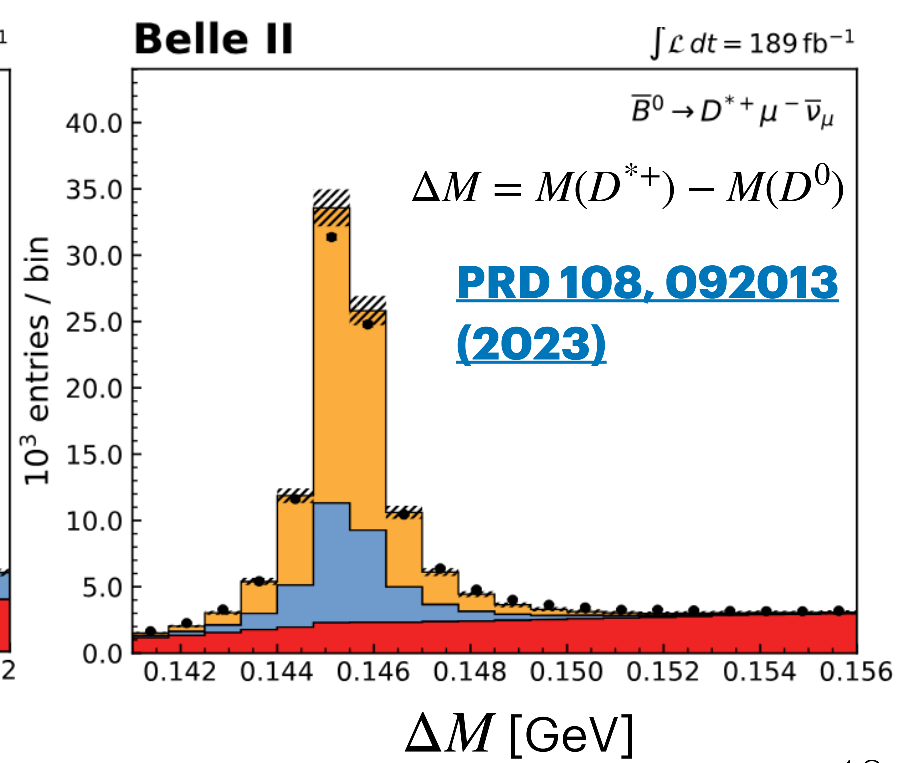
Reconstruct the kinematic variables:
w and 3 helicity angles, $cos\theta_\ell$, $cos\theta_v$ and χ.

$w = E_{D*}/M^*_D$

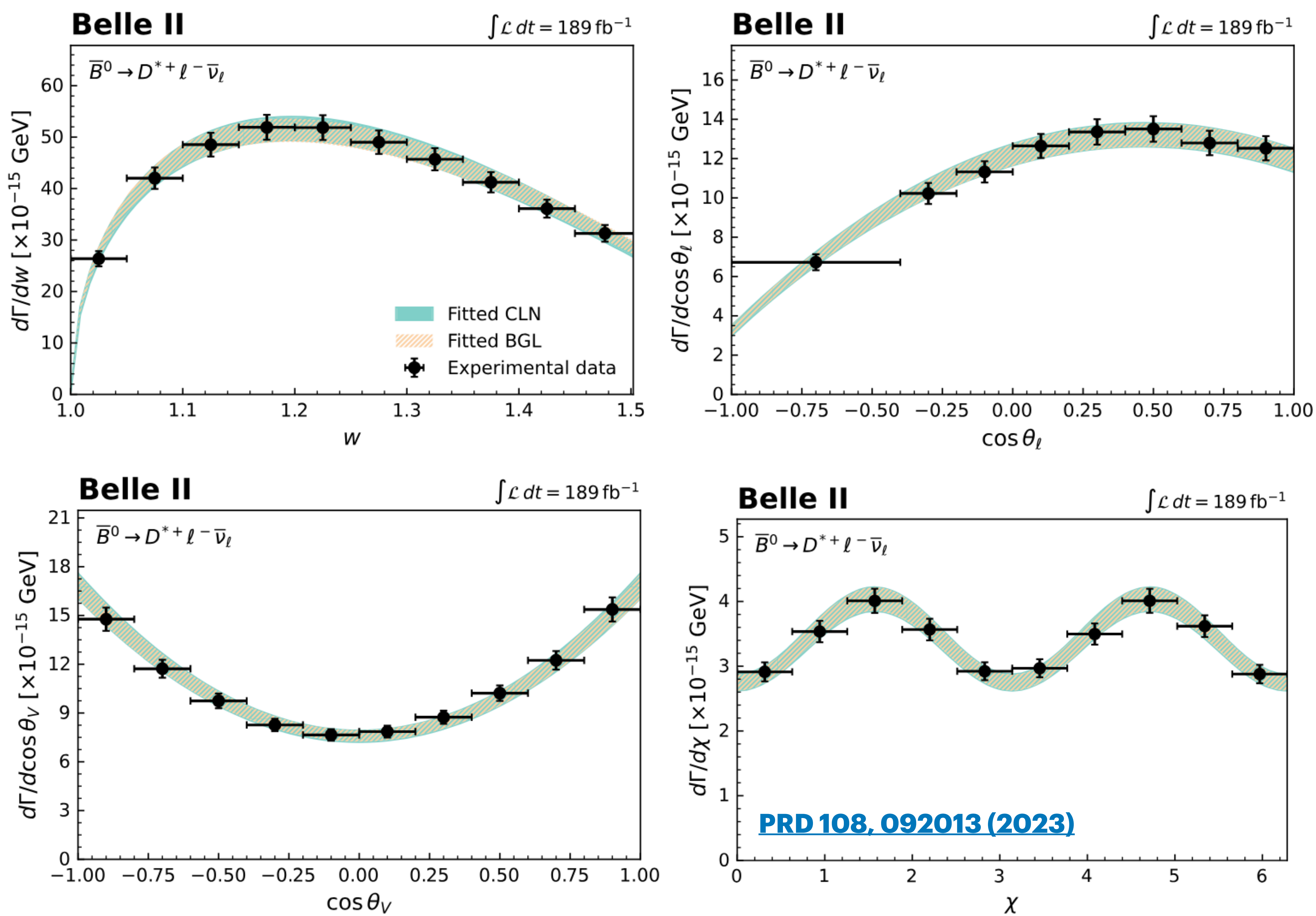
Extract the signal yields with fit to $cos\theta_{BY}$ and ΔM
in bins of w, $cos\theta_\ell$, $cos\theta_v$ and χ, to reconstruct 1D signal distributions.

Unfold the reconstructed distributions from experimental effects (efficiencies and resolutions).





Unfolded distributions



Fit the unfolded distributions with different form-factor model to obtain $|V_{cb}|$.

Results

$$\mathscr{B}(\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell) : (4.922 \pm 0.023(stat) \pm 0.220(syst))\,\%$$

Compatible with the current WA: $(4.97 \pm 0.12)\,\%$

$$|V_{cb}|_{BGL} = (40.57 \pm 0.31(stat) \pm 0.95(syst) \pm 0.58(th)) \cdot 10^{-3}$$

Compatible with the exclusive (inclusive) WA: 1.5σ (1.3σ)

$$|V_{cb}|_{CLN} = (40.13 \pm 0.27(stat) \pm 0.93(syst) \pm 0.58(th)) \cdot 10^{-3}$$

Compatible with the exclusive (inclusive) WA: 1.1σ (1.6σ)

Use FNAL/MILC lattice QCD data at zero recoil ($w = 1$) for normalisation.
BGL truncated using nested hypothesis test: BGL(1,2,2).

LFU test by comparing separated results for electrons and muons:

$$R_{e/\mu} = 0.998 \pm 0.009(stat) \pm 0.020(syst)$$

$$\Delta A_{FB} = (-17 \pm 16(stat) \pm 16(syst)) \cdot 10^{-3}$$

$$\Delta F_L = (0.006 \pm 0.007(stat) \pm 0.005(syst)) \cdot 10^{-3}$$

No deviations observed from the SM.

Measurement limited by systematic uncertainties:

1) slow-pion reconstruction efficiency $\to$ 1.5% on $|V_{cb}|$

2) $f_{+0} = \dfrac{\mathscr{B}(\Upsilon(4S) \to B^+B^-)}{\mathscr{B}(\Upsilon(4S) \to B^0\bar{B}^0)}$ $\to$ 1.3% on $|V_{cb}|$

$|V_{cb}|$ from $B \to D\ell\nu$

More simpler on theoretical side respect to $B \to D^*\ell\nu$ analyses.

Reconstruct both B^0 and B^+ decays from $D^0 \to K\pi$ and $D^- \to K\pi\pi$ final states.

Exploit isospin symmetry to analyze B^0 and B^+decays simultaneously and reduce experimental uncertainties.

Extract signal yields from fit to the $cos\theta_{BY}$ in 10 bins of w.

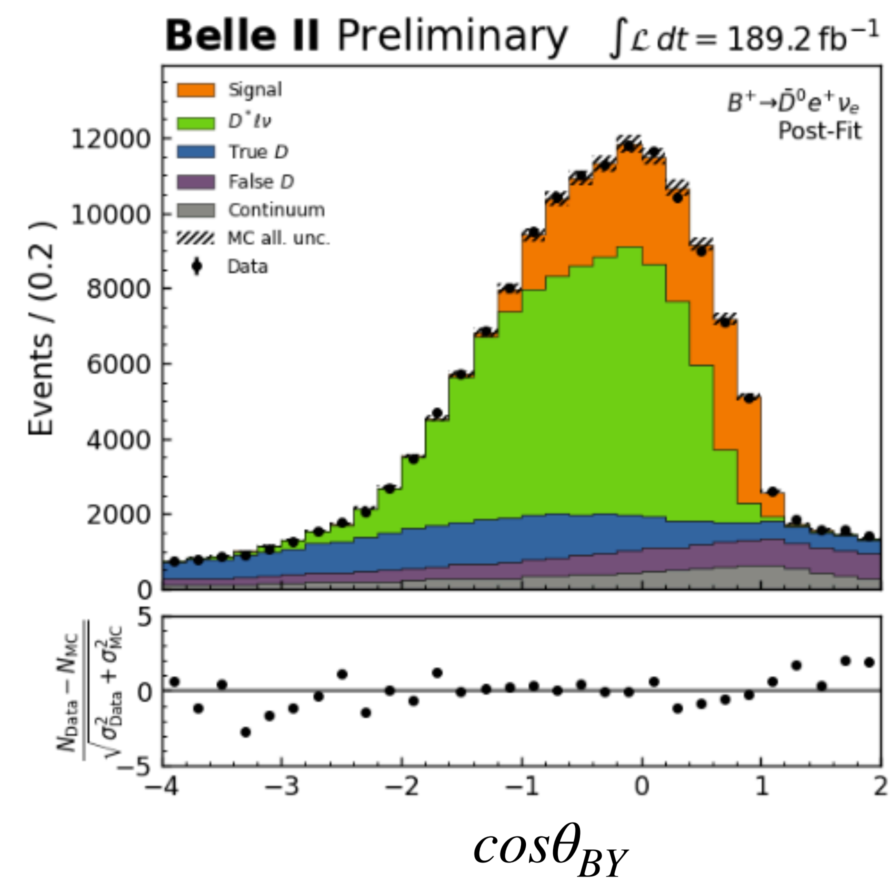
Unfold the reconstructed w distribution of the signal.

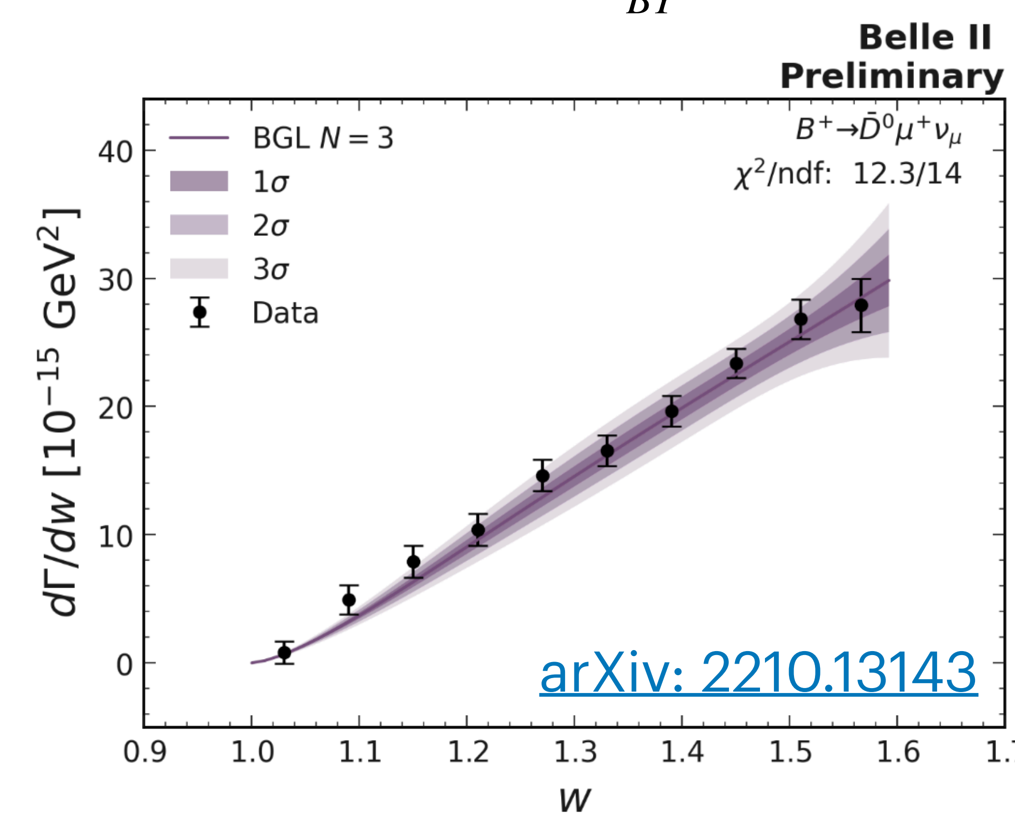
Preliminary result

$$|V_{cb}|_{BGL} = (38.28 \pm 1.16) \cdot 10^{-3}$$

Obtain a total uncertainty on $|V_{cb}|$ of ~ 3%.

Update to 365 fb^{-1} ongoing: expected ~2% on $|V_{cb}|$.





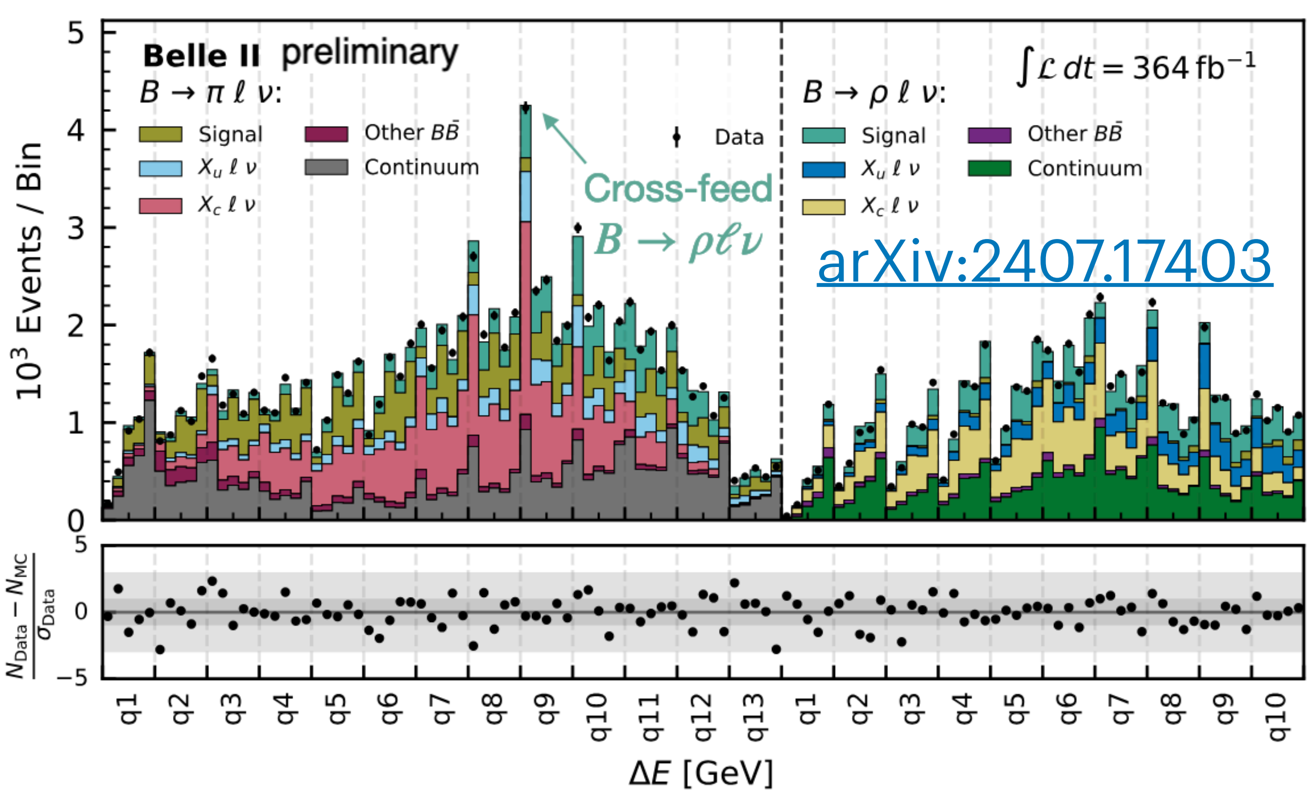
$|V_{ub}|$ from $B \to \pi/\rho\ell\nu$

Simultaneously extract signal yields via binned 3D fits using beam-constrained mass M_{bc} and energy difference ΔE in bins of $q^2 = (p_B - p_\pi)^2$.

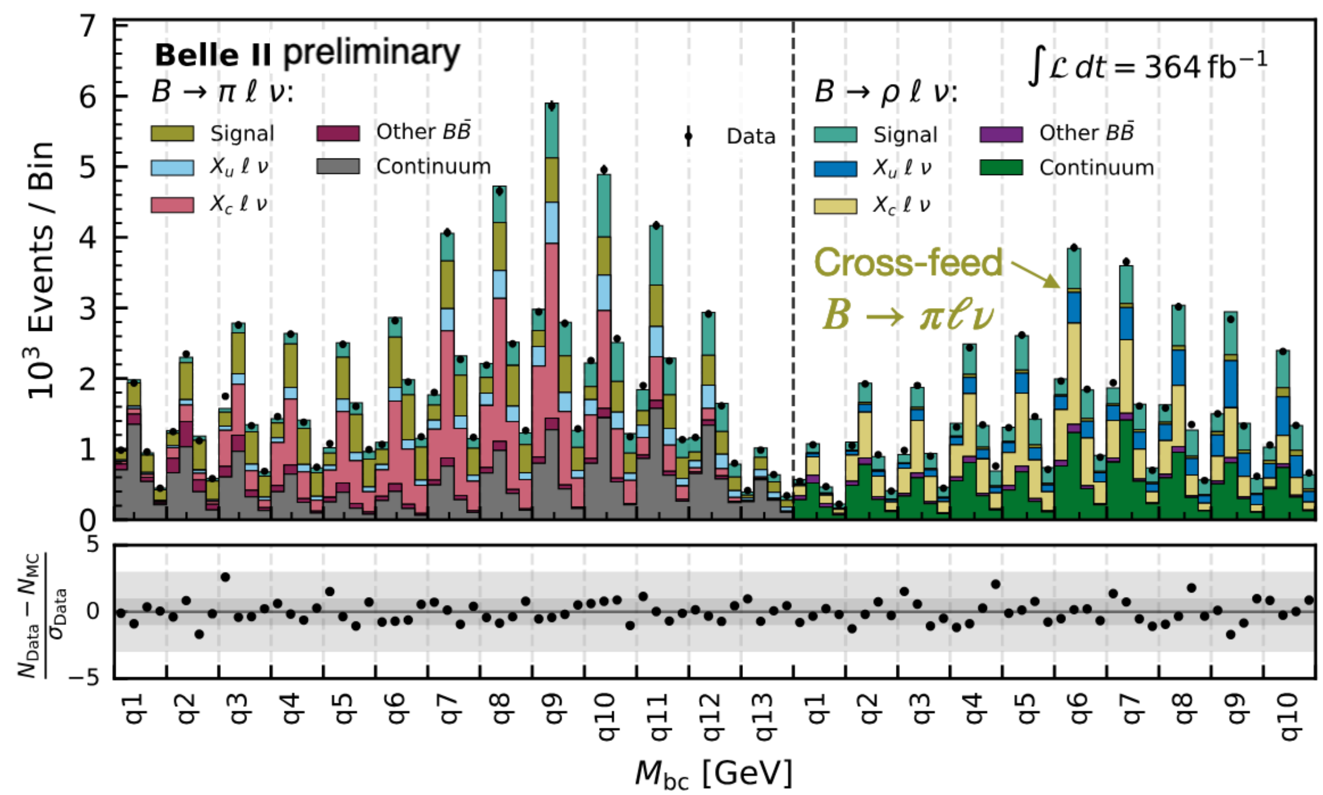
Large backgrounds from $e^+e^- \to q\bar{q}$ processes and other semileptonic $B \to X_c\ell\nu$ decays.

Take into account cross-feed signal yields and correlations between backgrounds.

$$\Delta E = E_B^* - E_{\text{beam}}^*$$



$$M_{bc} = \sqrt{E_{\text{beam}}^{*2} - |\vec{p}_B^{\,*}|^2}$$



$|V_{ub}|$ from $B \to \pi/\rho\ell\nu$

Convert to partial branching fractions using reconstruction efficiencies.

Total branching ratios consistent with world averages:

$$\mathcal{B}(B^0 \to \pi^-\ell^+\nu) = (1.516 \pm 0.042 \pm 0.059) \cdot 10^{-4}$$

$$\mathcal{B}(B^+ \to \rho^0\ell^+\nu) = (1.625 \pm 0.079 \pm 0.180) \cdot 10^{-4}$$

Determine $|V_{ub}|$ by fitting differential decay widths using the relevant form factor expansions with constraints from LQCD/LCSR:

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

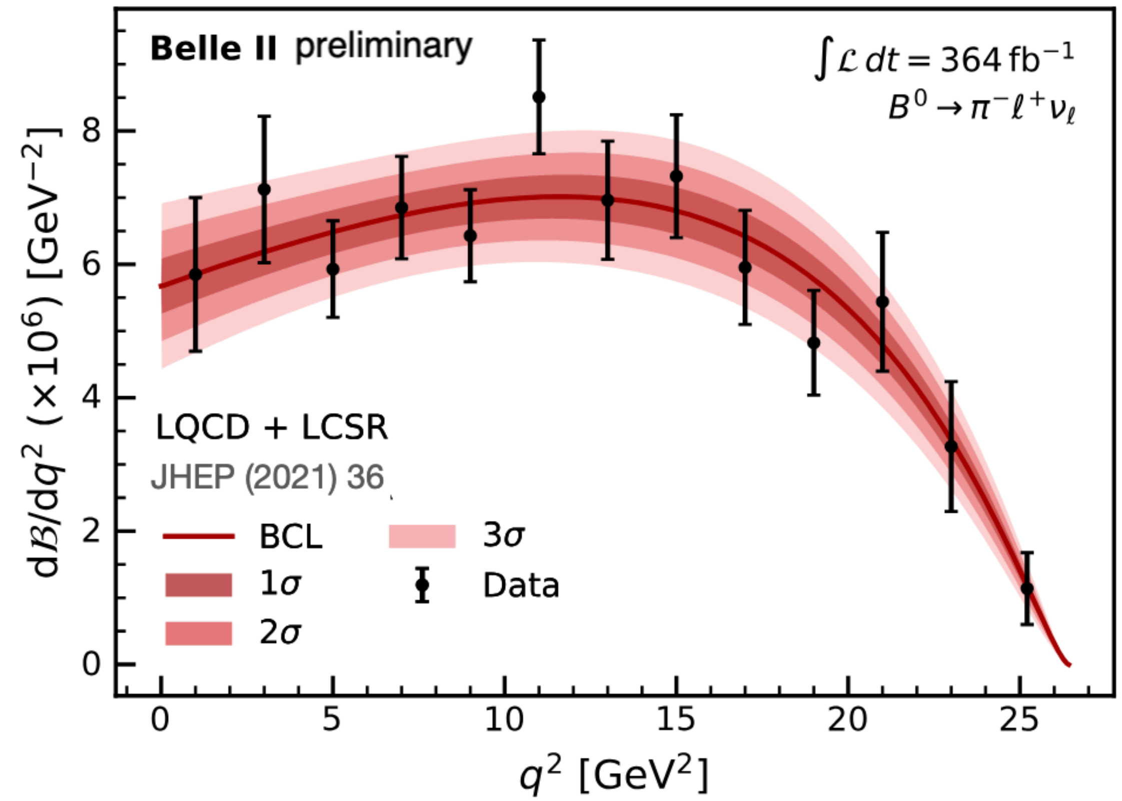
$$|V_{ub}|_{\text{LQCD+LCSR}} = (3.73 \pm 0.07 \pm 0.07 \pm 0.16) \cdot 10^{-3}$$

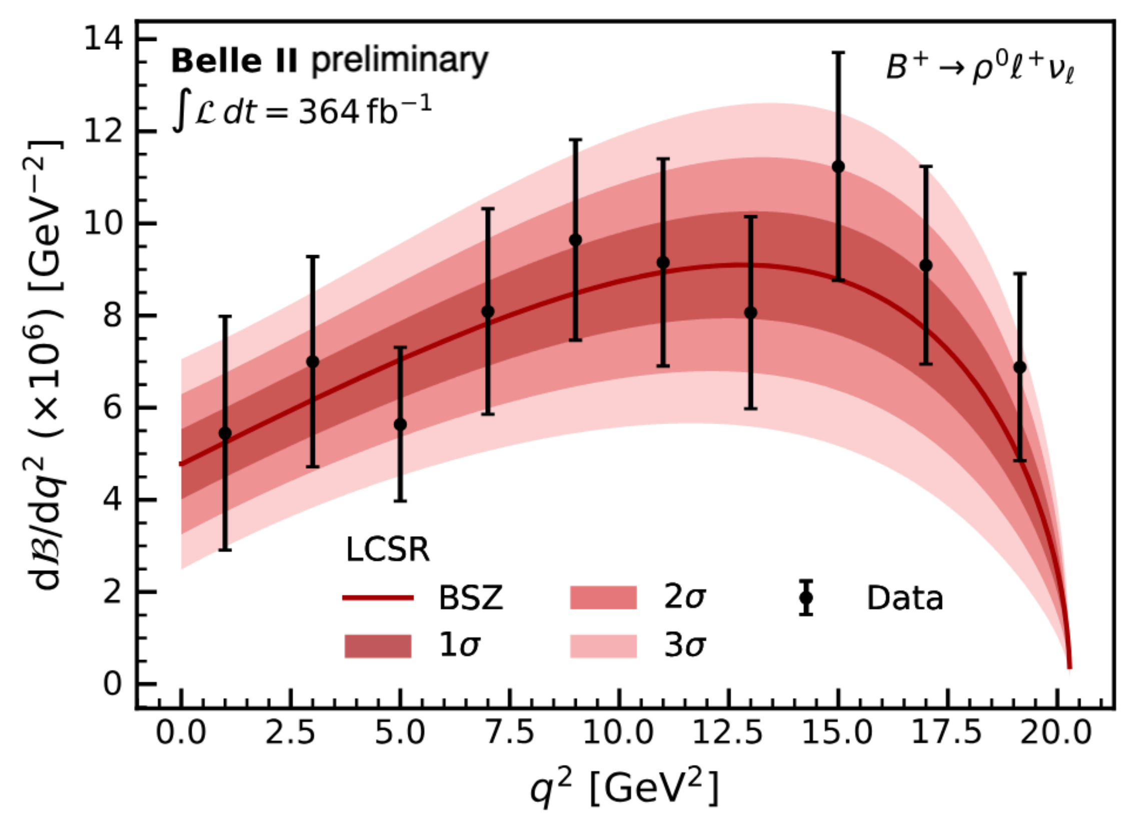
theory

$B^+ \to \rho^0\ell^+\nu$

$$|V_{ub}|_{\text{LCSR}} = (3.19 \pm 0.12 \pm 0.17 \pm 0.26) \cdot 10^{-3}$$

In agreement with exclusive world average.

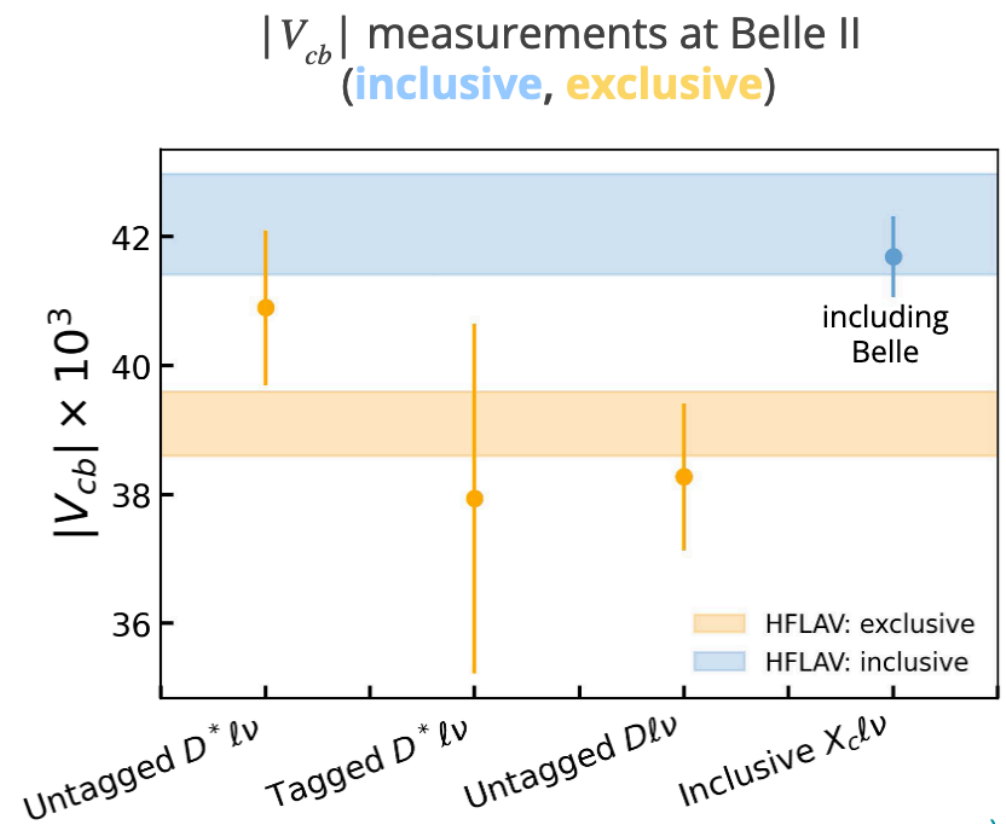


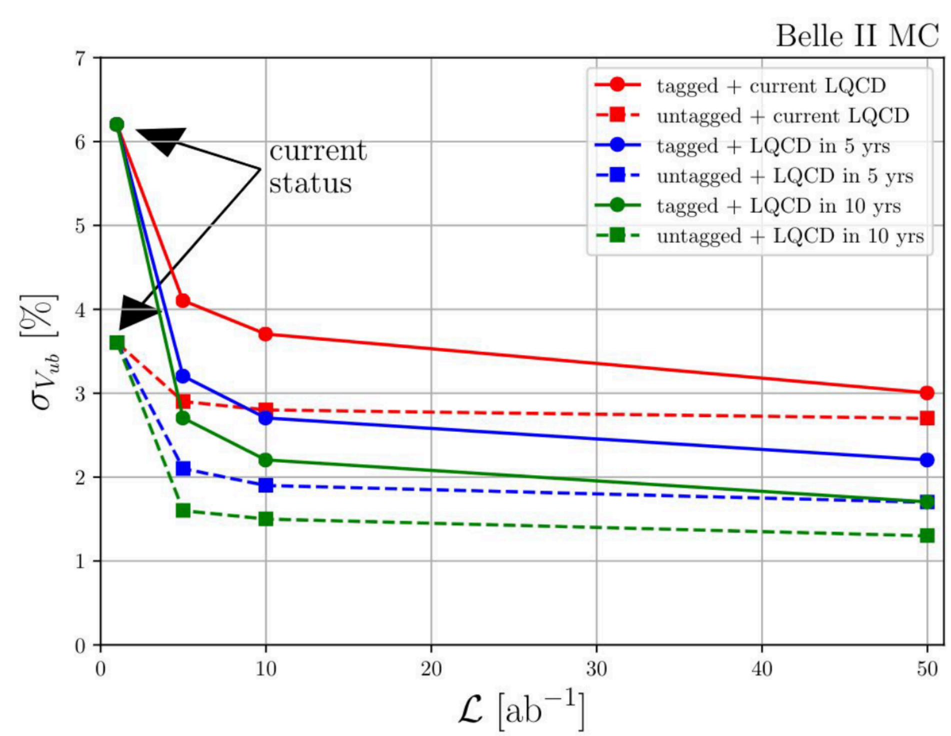


arXiv:2407.17403

Prospects

- Belle II can be deliver more precise measurements of ϕ_1, ϕ_2, ϕ_3 with the current data set corresponding to ~542 fb^{-1} .
- $|V_{ub}|$ and $|V_{cb}|$ at Belle II:
  - Aim to measure $|V_{cb}|$ at ~1% precision with larger data set (Snowmass white paper).
  - Explore simultaneous determination of inclusive and exclusive $|V_{ub}|$.
  - Move towards direct measurements of $|V_{ub}|/|V_{cb}|$.
- First simultaneous analysis of $B \to D\ell\nu$ and $B \to D^*\ell\nu$ is ongoing at Belle II: very promising analysis w/ different sources of systematic uncertainties.





Summary

Belle (II) is one of the primary experiments for testing the CKM matrix:

- Opportunity to test all the UT angles: unique capability to study in consistent way all $B \to \pi\pi$ towards ϕ_2. Results competitive with the SM predictions.

- Notable involvement in the measurement of CKM couplings: $|V_{ub}|$ and $|V_{cb}|$.

- Tension between different determinations of $|V_{xb}|$ still exists:
  - From theory: improved inputs from LQCD will be fundamental.
  - Complementary methods must to be explored: a simultaneous analysis of $B \to D\ell\nu$ and $B \to D^*\ell\nu$ can give an important contribution on the understanding of this tension.

Backup

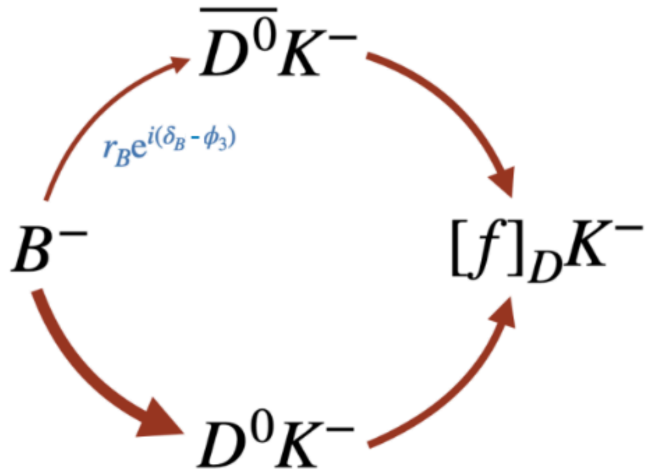
ϕ_3 from Belle + Belle II combination

ϕ_3: phase between $b \to u$ and $b \to c$ transitions.

Interference between two decays to same final states gives access to the phase:

Current WA dominated by LHCb:

$\phi_3[°] = 65.9^{+3.3}_{-3.5}$



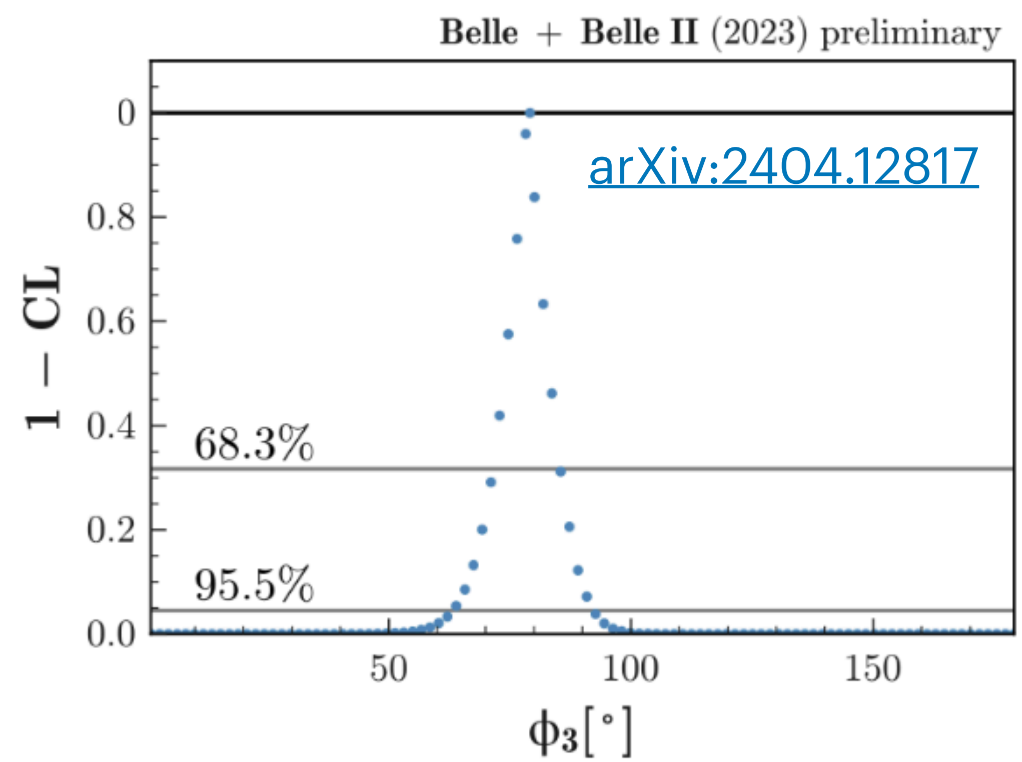
$$\frac{\mathcal{A}^{\text{suppr.}}(B^- \to \overline{D}^0K^-)}{\mathcal{A}^{\text{favor.}}(B^- \to D^0K^-)} = r_B e^{i(\delta_B-\phi_3)}$$

Various approaches — different D final states:

- Self-congjugate final states $D \to K^0_S h^+h^-(\pi^0)$
- Cabibbo-suppressed decays $D \to K^0_S K^\pm \pi^\mp, D \to K^+\pi^-(\pi^0)$
- CP eigenstates $D \to K^+K^-, K^0_S\pi^0$

First combination of all Belle and Belle II ϕ_3-measurements:

$\phi_3[°] = 78.6^{+7.2}_{-7.3}$



$\sin 2\phi_1$ from $B^0 \to \eta' K_S^0$ decays

Gluonic penguin modes suppressed in SM, sensitive to BSM. Reliable theory prediction <1%.

$C \simeq 0$, $S \simeq \sin 2\phi_1$ in SM

$$\mathscr{A}_{CP}(\Delta t) = \frac{\Gamma(\overline{B}^0 \to f_{CP}) - \Gamma(B^0 \to f_{CP})}{\Gamma(\overline{B}^0 \to f_{CP}) + \Gamma(B^0 \to f_{CP})}(\Delta t) = S \sin(\Delta m \Delta t) - C \cos(\Delta m \Delta t)$$

Challenges:

— hadronic final state with neutrals

— large background from continuum

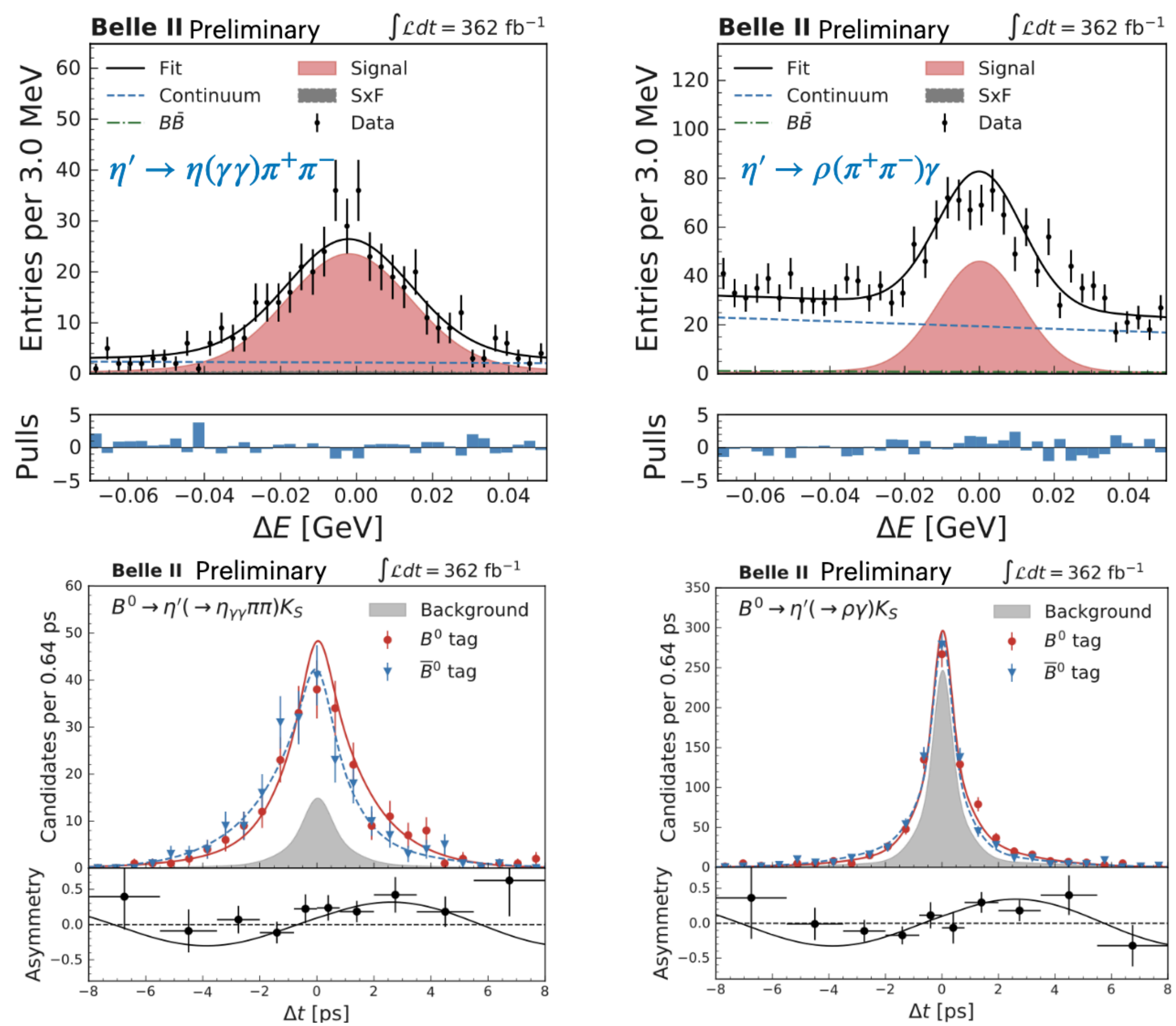
Signal extraction via fit to ΔE, M_{bc}, CS, Δt.

$$S = 0.67 \pm 0.10 \pm 0.04$$

$$C = -0.19 \pm 0.08 \pm 0.03$$

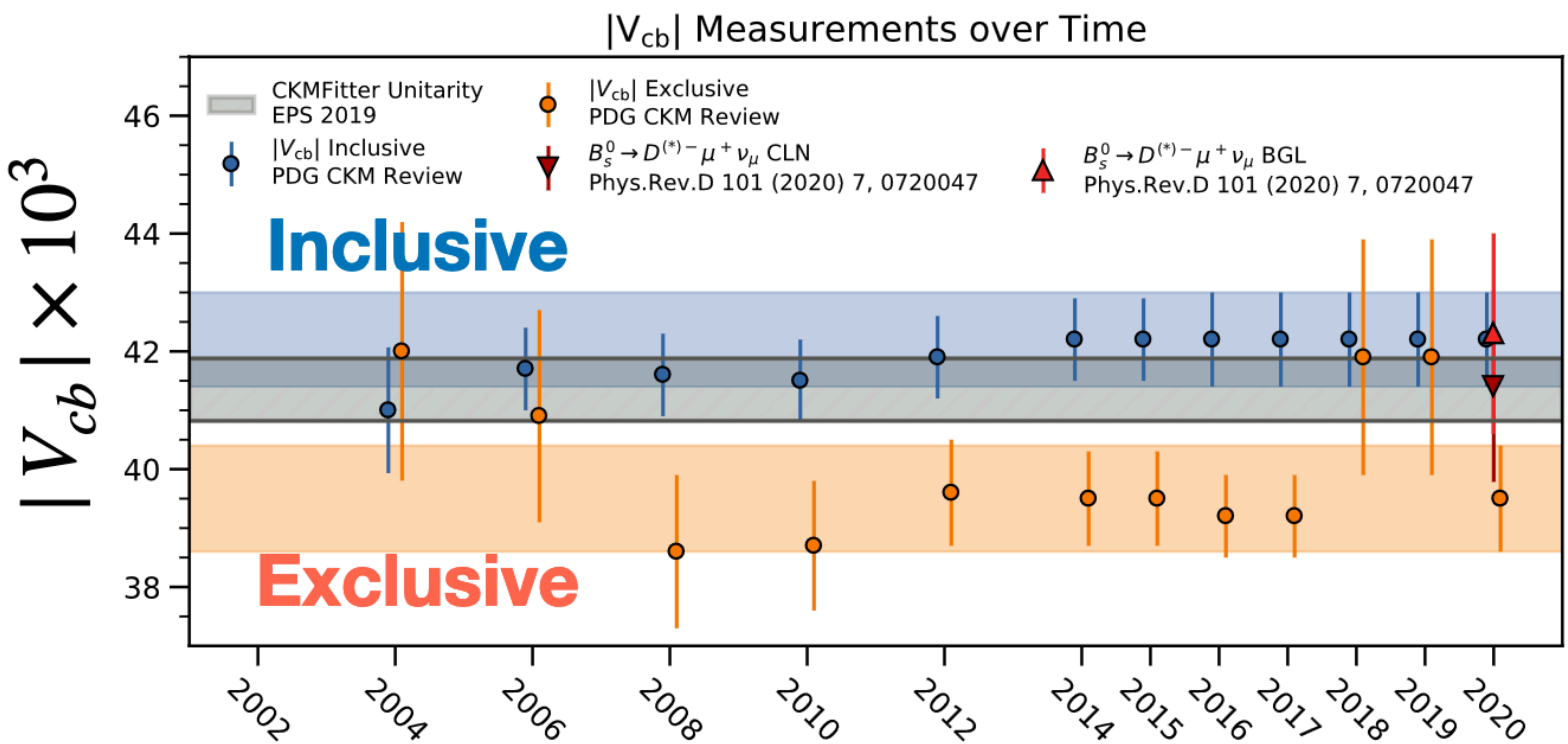
HFLAV: $S = 0.63 \pm 0.06$, $C = -0.05 \pm 0.04$

Precision comparable with Belle/BaBar in spite of smaller sample.



arXiv:2402.03713

$|V_{cb}|$ measurements



Discrepancy of the methods spoils the accuracy of the determination.

Update to 365 fb^{-1} ongoing

An analysis on the full data set collected by Belle II between 2019 and 2022 is ongoing.
Improved selection and better control of systematic uncertainties:

	$\|V_{cb,BGL}\|$ [%]	$\|V_{cb,BCL}\|$ [%]
Stat. Error	0.7	0.6
MC Stat. Error	0.4	0.3
N_{bb}	0.8	0.8
f_{00}/f_{+-}	< 0.1	< 0.1
$\mathcal{B}(D \to K\pi(\pi))$	0.4	0.4
Selection	0.2	0.2
$\mathcal{B}(B \to X_c \ell \nu)$	0.2	0.1
LeptonID	0.1	0.1
KaonID	0.4	0.4
Tracking efficiency	0.5	0.5
$B \to D\ell\nu_\ell$ form factor	0.8	0.4
$B \to D^*\ell\nu_\ell$ form factor	0.1	0.1
$\cos\theta_{BY}$ background modelling	0.2	0.2
w background modelling	0.5	0.4
$\tau_{B^{0/\pm}}$	0.1	0.1
Total systematic	1.5	1.4
Theory PRD 79, 013008, PRD 93, 119906	1.3	1.2
Total	2.1	1.9

The uncertainty on f_{+-}/f_{00} cancel out by assuming isospin symmetry between B^0 and B^+ samples.

Theory contribution: lattice point at non-zero recoil lattice QCD calculations.

Expected competitive result on $|V_{cb}|$ with a total uncertainty of ~ 2%.

Expected also competitive result on the branching-fraction measurements.

Global analysis: potential

From a development of the analysis in simulation can expect:

$$|V_{cb}|_{BGL} = (XXX \pm 0.20 \pm 0.54 \pm 0.28) \cdot 10^{-3}$$

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

$$\mathscr{B}(B^+ \to \overline{D}^{*0} \ell^+ \nu) = (XXX \pm 0.02 \pm 0.17)\ \%$$

$$\mathscr{B}(B^0 \to D^- \ell^+ \nu) = (XXX \pm 0.01 \pm 0.05 \pm 0.02)\ \%$$

$$\mathscr{B}(B^0 \to D^{*-} \ell^+ \nu) = (XXX \pm 0.02 \pm 0.15 \pm 0.05)\ \%$$

$$A_{FB} = (XXX \pm 0.5 \pm 0.4)\ \%$$

$$F_L^{D*} = (XXX \pm 0.7 \pm 0.7)\ \%$$

$$f_{+-}/f_{00} = XXX \pm 0.007 \pm 0.025 \pm 0.024$$

Results competitive with world's best measurements.

BR and f_{+-}/f_{00} expected uncertainties

Measure the $\mathscr{B}(B \to D\ell\nu)$ and $\mathscr{B}(B \to D^*\ell\nu)$ by integrating over all the w range the differential branching fractions obtained from our model-independent observables in each w bins.

	Relative uncertainties [%] on $\mathscr{B}(B \to D\ell\nu)$	Relative uncertainties [%] on $\mathscr{B}(B \to D^*\ell\nu)$	Relative uncertainties [%] on f_{+-}/f_{00}
NBB	1.5	1.5	< 0.1
BR(D decays)	1.0	0.7	1.9
Lifetime ratio	0.2	0.2	0.4
track efficiency	0.8	0.8	0.2
BR(D + gap)**	1.3	1.2	1.1
Backgr. model	0.7	2.2	0.4
Templates stat.	0.3	0.2	0.3
Fit bias	0.1	0.1	< 0.1
TOTAL SYST	2.5	3.0	2.3
Coulomb factor (th. unc.)	1.0	1.1	2.3
STAT	0.5	0.4	0.7
TOTAL	2.7	3.2	3.3

BR and f_{+-}/f_{00} expected uncertainties

Compare the uncertainties of $\mathscr{B}(B \to D\ell\nu)$, $\mathscr{B}(B \to D^*\ell\nu)$ and f_{+-}/f_{00} with the best measurements.

	Expected results	Best measurements
$\mathscr{B}(B^+ \to \overline{D}^0\ell^+\nu)$	$XXX \pm 0.01(stat) \pm 0.06(syst)$	BaBar $2.34 \pm 0.03(stat) \pm 0.13(syst)$ Phys.Rev.D 79 (2009) 012002
$\mathscr{B}(B^+ \to \overline{D}^{*0}\ell^+\nu)$	$XXX \pm 0.02(stat) \pm 0.17(syst)$	BaBar $5.40 \pm 0.02(stat) \pm 0.21(syst)$ Phys.Rev.D 79 (2009) 012002
$\mathscr{B}(B^0 \to D^-\ell^+\nu)$	$XXX \pm 0.01(stat) \pm 0.05(syst) \pm 0.02(th)$	Belle $2.31 \pm 0.03(stat) \pm 0.11(syst)$ Phys. Rev. D 93, 032006
$\mathscr{B}(B^0 \to D^{*-}\ell^+\nu)$	$XXX \pm 0.02(stat) \pm 0.15(syst) \pm 0.05(th)$	Belle $4.90 \pm 0.02(stat) \pm 0.16(syst)$ Phys. Rev. D 100, 052007
f_{+-}/f_{00}	$XXX \pm 0.007(stat) \pm 0.025(syst) \pm 0.024(th)$	Belle $1.065 \pm 0.012(stat) \pm 0.019(syst) \pm 0.047(th)$ Phys. Rev. D 107, L031102

Th. uncertainty from Coulomb factor.

Measurements competitive with the world's best.

Expected uncertainties on FF and $|V_{cb}|$

	Rel. unc. [%] on	Uncertainty $[10^{-2}]$ on				
	$|V_{cb}|$	$a_1^{f_+}$	a_0^g	a_1^g	a_1^f	a_1^F
NBB	0.7	< 0.01	< 0.01	0.1	< 0.1	< 0.01
BR(D decays)	0.6	0.02	0.01	0.4	< 0.1	0.01
Lifetime ratio	0.1	< 0.01	< 0.01	< 0.1	< 0.1	< 0.01
track efficiency	0.4	< 0.01	< 0.01	0.1	< 0.1	< 0.01
BR(D + gap)**	0.6	0.01	0.01	0.5	0.1	0.01
Backgr. modelling	0.5	0.08	0.10	3.5	0.8	0.05
Templates stat.	0.1	0.02	0.03	0.7	0.2	0.01
Fit bias	< 0.1	< 0.01	< 0.01	0.1	0.03	< 0.01
TOTAL SYST	1.3	0.11	0.13	4.6	1.1	0.06
Coulomb factor (th. unc.)	0.5	< 0.01	< 0.01	0.1	< 0.1	< 0.01
STAT	0.5	0.09	0.10	3.2	0.9	0.03
Lattice points	0.7	0.13	0.06	3.2	0.7	0.02
TOTAL	1.7	0.20	0.19	7.4	2.0	0.08

Compare the expected uncertainty on $|V_{cb}|$ with the latest Belle II measurement (PRD 108, 092013).

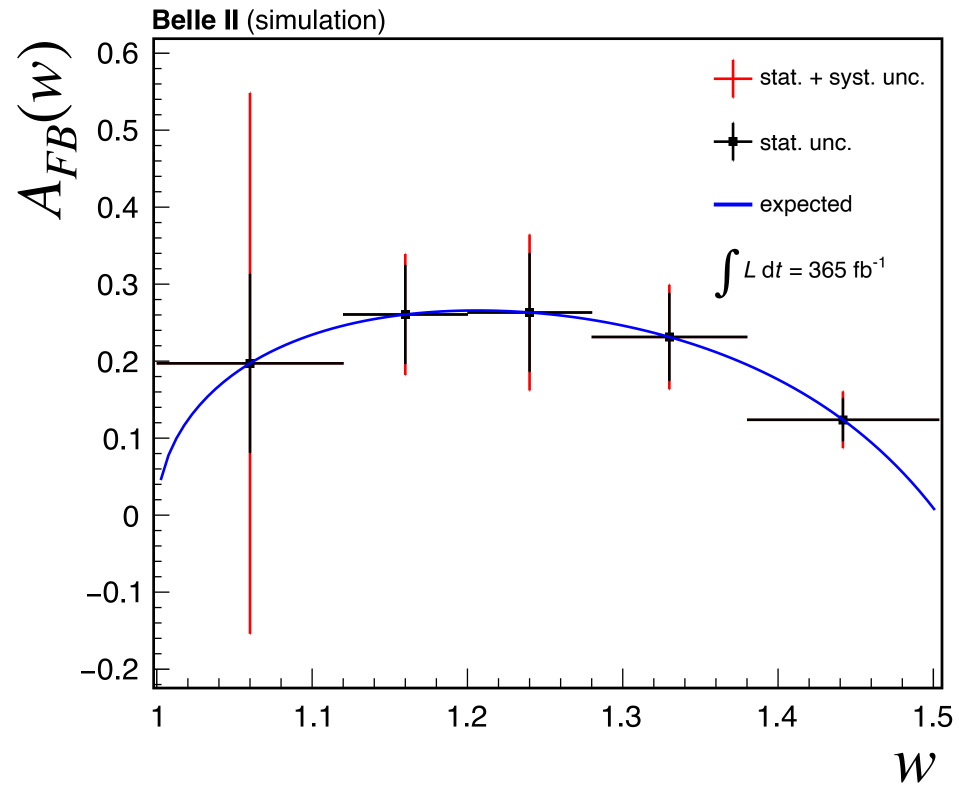
	$|V_{cb}|\,[10^{-3}]$
My work	$XXX \pm 0.20 \pm 0.54 \pm 0.28$
Belle II (2023)	$40.57 \pm 0.31 \pm 0.95 \pm 0.58$

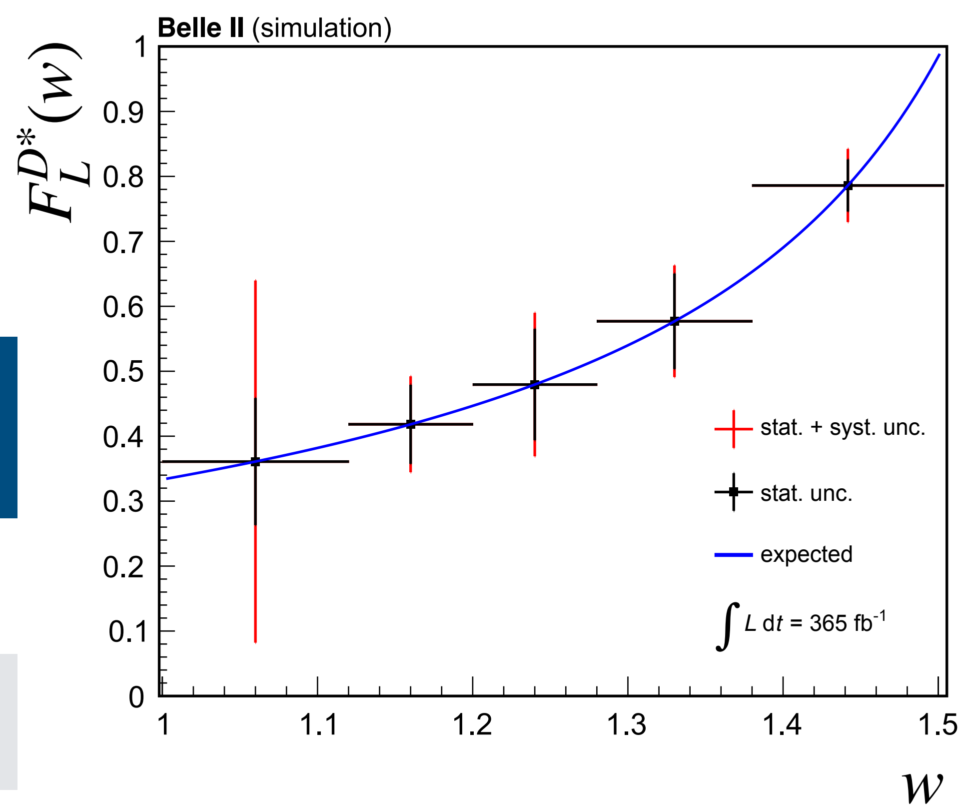
Expected competitive result with the world's best measurements.

A_{FB} and $F_L^{D^*}$

	$A_{FB}[10^{-2}]$	$F_L^{D^*}[10^{-2}]$
NBB	<0.01	<0.01
BR(D decays)	0.01	0.01
Lifetime ratio	<0.01	<0.01
track efficiency	<0.01	<0.01
BR(D + gap)**	0.03	0.02
Backgr. model	0.31	0.56
Templates stat.	0.26	0.35
Fit bias	0.02	0.05
TOTAL SYST	0.41	0.66
Coulomb factor (th. unc.)	<0.01	<0.01
STAT	0.47	0.70
TOTAL	0.62	0.94

	My work	**Belle II (2023)**
A_{FB}	$XXXX \pm 0.005 \pm 0.004$	$0.228 \pm 0.012 \pm 0.018$ (e mode) $0.211 \pm 0.011 \pm 0.021$ (μ mode)
$F_L^{D^*}$	$XXXX \pm 0.007 \pm 0.007$	$0.520 \pm 0.005 \pm 0.005$ (e mode) $0.527 \pm 0.005 \pm 0.005$ (μ mode)



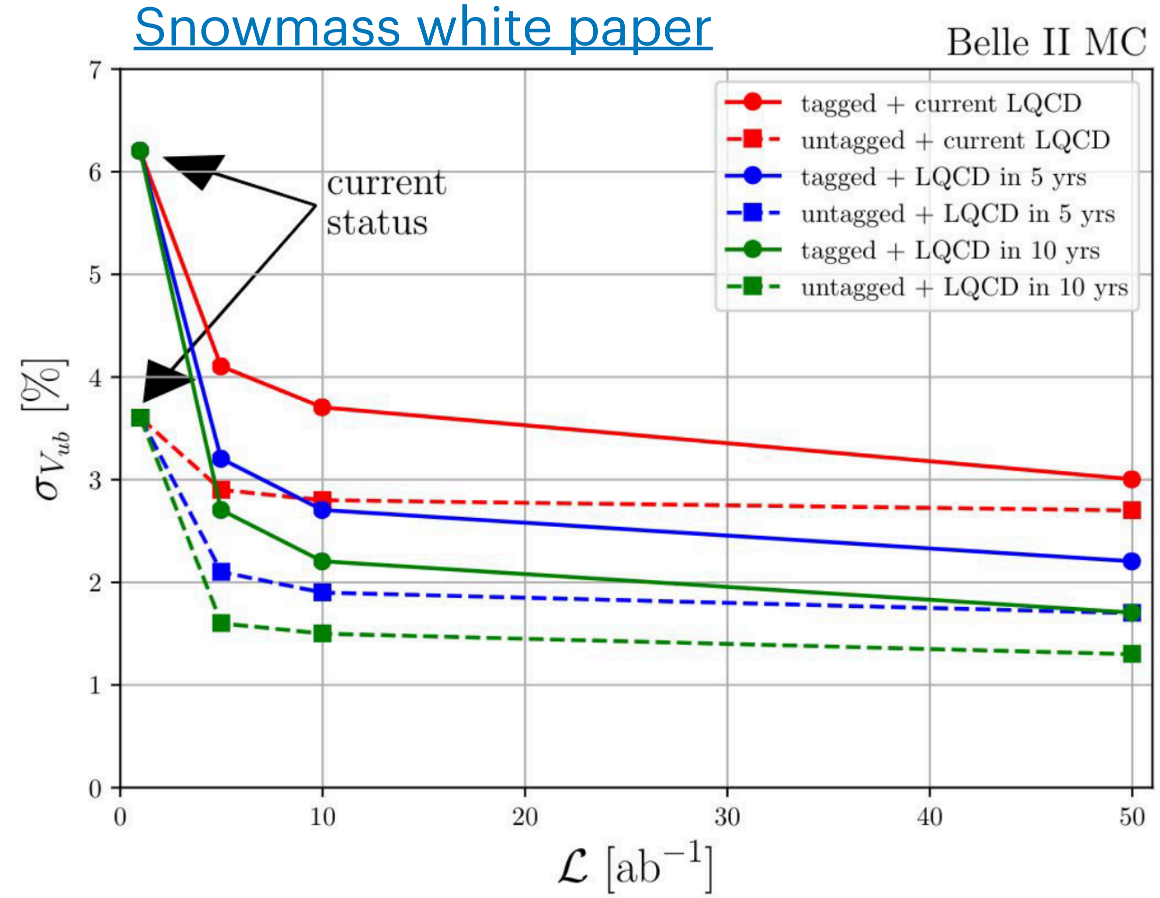


Expected competitive results with world's best measurements.
Can also measure separately for electron and muon for LFU.

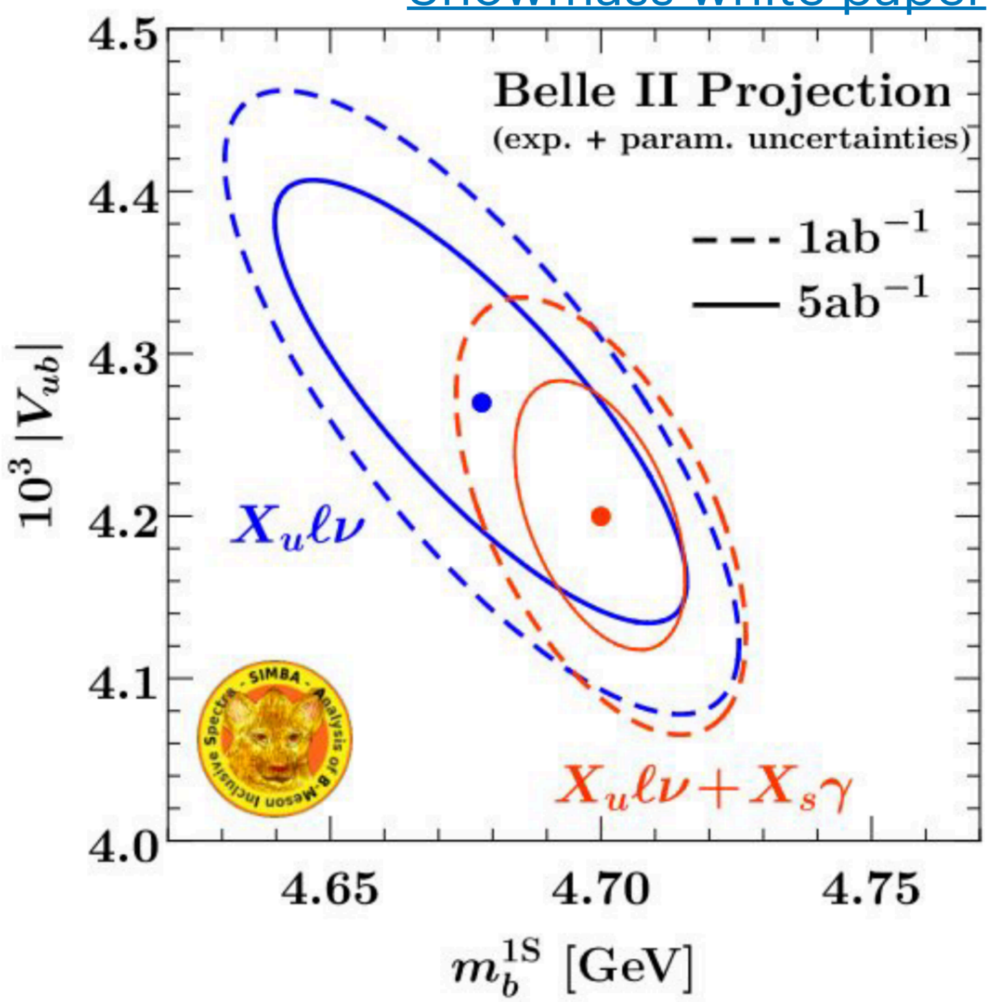
Prospects: $|V_{ub}|$ at Belle II

- Belle II will double the precision on exclusive $|V_{ub}|$ at least 3%, even assuming no improvements in form factors uncertainties.
- Move towards direct measurements of $|V_{ub}|/|V_{cb}|$.

Snowmass white paper



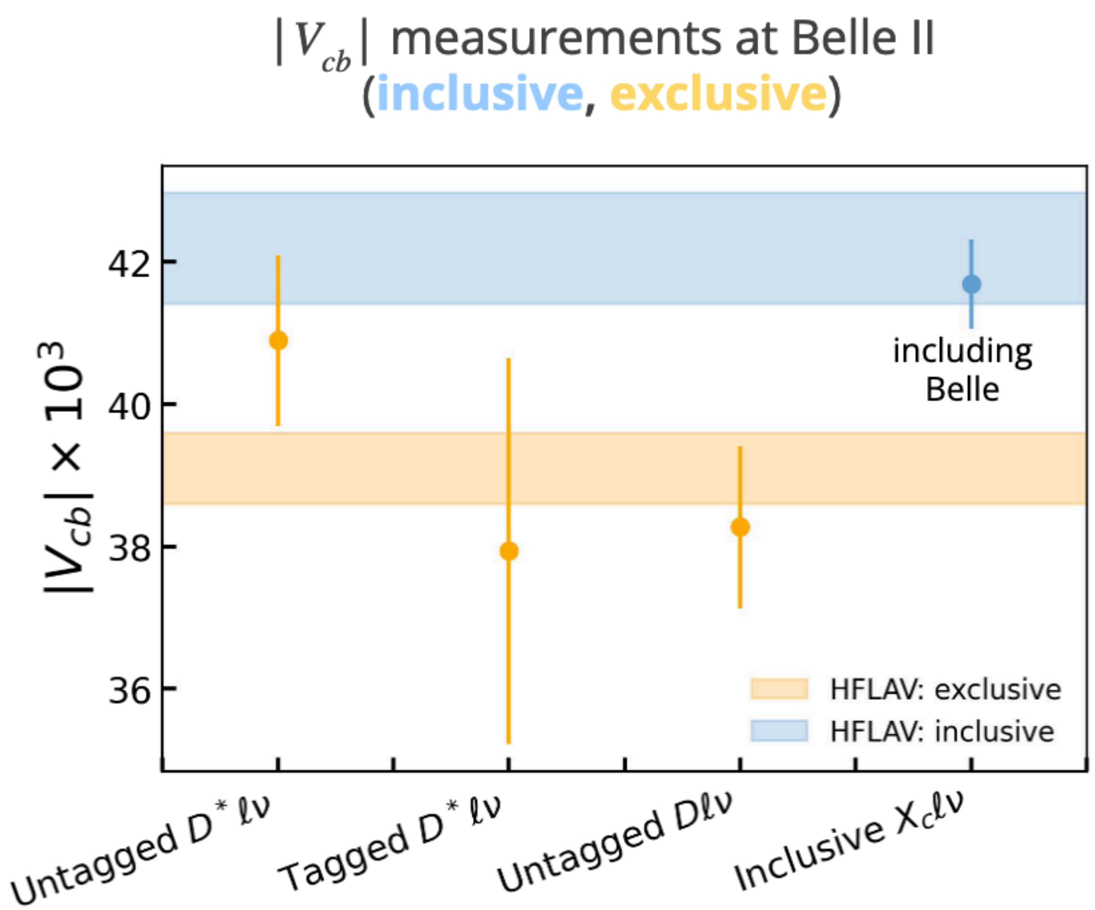
Snowmass white paper



- Inclusive $|V_{ub}|$ is very challenging: expected to reach ~3% precision with larger sample size and improved $B-$tagging.
- Explore simultaneous determination of inclusive and exclusive $|V_{ub}|$.

Prospects: $|V_{cb}|$ at Belle II

- First exclusive measurement at Belle II: exploit statistical power of untagged measurements.
- Inclusive effort started with measurement of q^2 moments in $B \to X_c \ell \nu$ (PRD.107.072002)
- Aim to measure $|V_{cb}|$ at ~1% precision with larger data set (Snowmass white paper).



- First simultaneous analysis of $B \to D\ell\nu$ and $B \to D^*\ell\nu$ is ongoing at Belle II. Very promising with different sources of systematic uncertainties respect to the ongoing analyses.