Measurements of hadronic, leptonic, and semi-leptonic B decays at Belle and Belle II

59th Rencontres de Moriond | QCD & High Energy Interactions

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On behalf of the Belle and Belle II collaborations

Results for Moriond QCD 2025

All results are new since Moriond 2024

Hadronic decays of B mesons

- $B^0 \to \rho^+\rho^-$
- $B^0 \to \bar{\Lambda}^0\Omega^{(*)0}$

Missing energies leptonic decays of B mesons

- $B \to \tau\nu_\tau$

Missing energies semi-leptonic decays of B mesons

- $R(D^+), R(D^{*+})$
- $|V_{cb}|$ from $B \to D\ell\nu$

Datasets for these measurements

Belle	$\mathcal{L}_{\text{intg}}^{\Upsilon(4S)} = 711\ \text{fb}^{-1}$	(1999 - 2010)
Belle II	$\mathcal{L}_{\text{intg}}^{\Upsilon(4S)} = 365\ \text{fb}^{-1}\ (\text{Run 1})$	**(2019 - 2022)**

All Belle (II) analyses are performed using opensourced Belle II software framework [Comput Softw Big Sci 3, 1 (2019)]

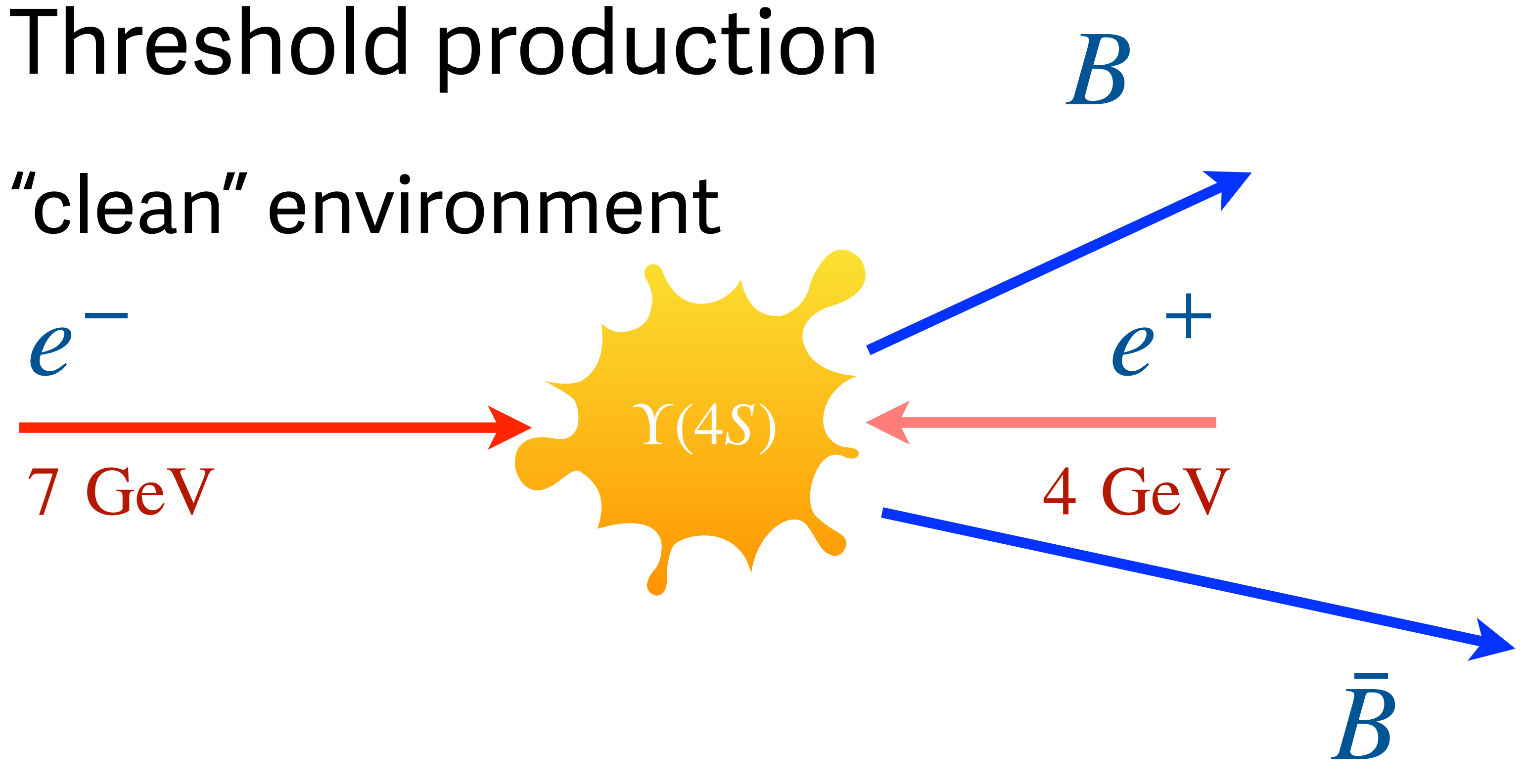
Other interesting results from Belle II:

Bianca Scavino, Debjit Ghosh, Zuzana Gruberova (tomorrow, morning session)

Kinematics at B factories

Threshold production

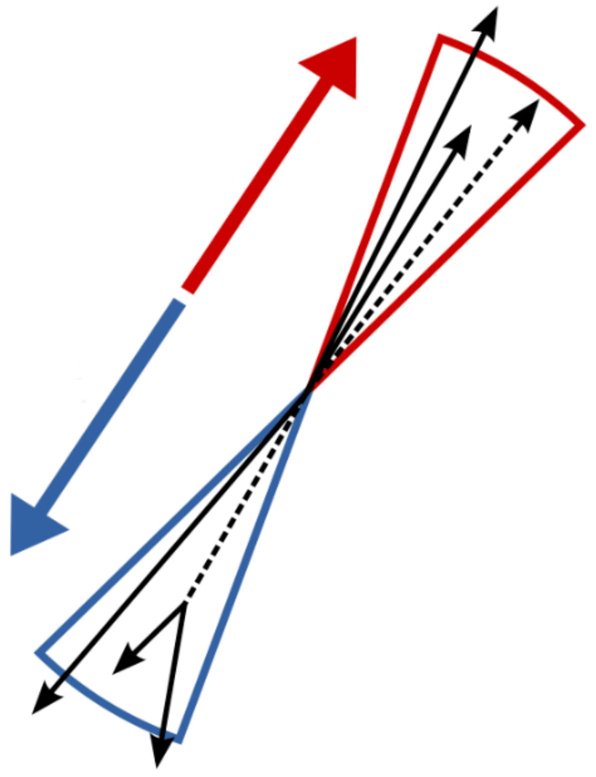
"clean" environment

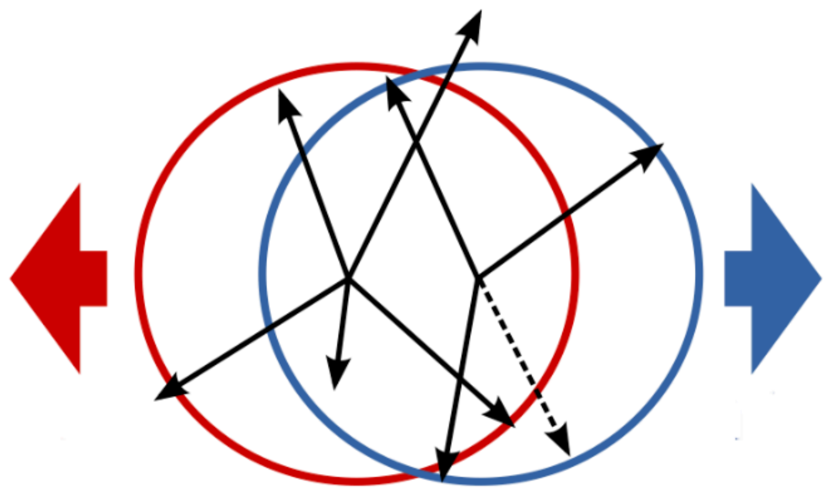


$$M_{bc} = \sqrt{E_{\rm beam}^{*2}/c^4 - p_B^{*2}/c^2}$$

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

Event topology in $\Upsilon(4S)$ frame





Isotropic distribution of B

Jet-like topology

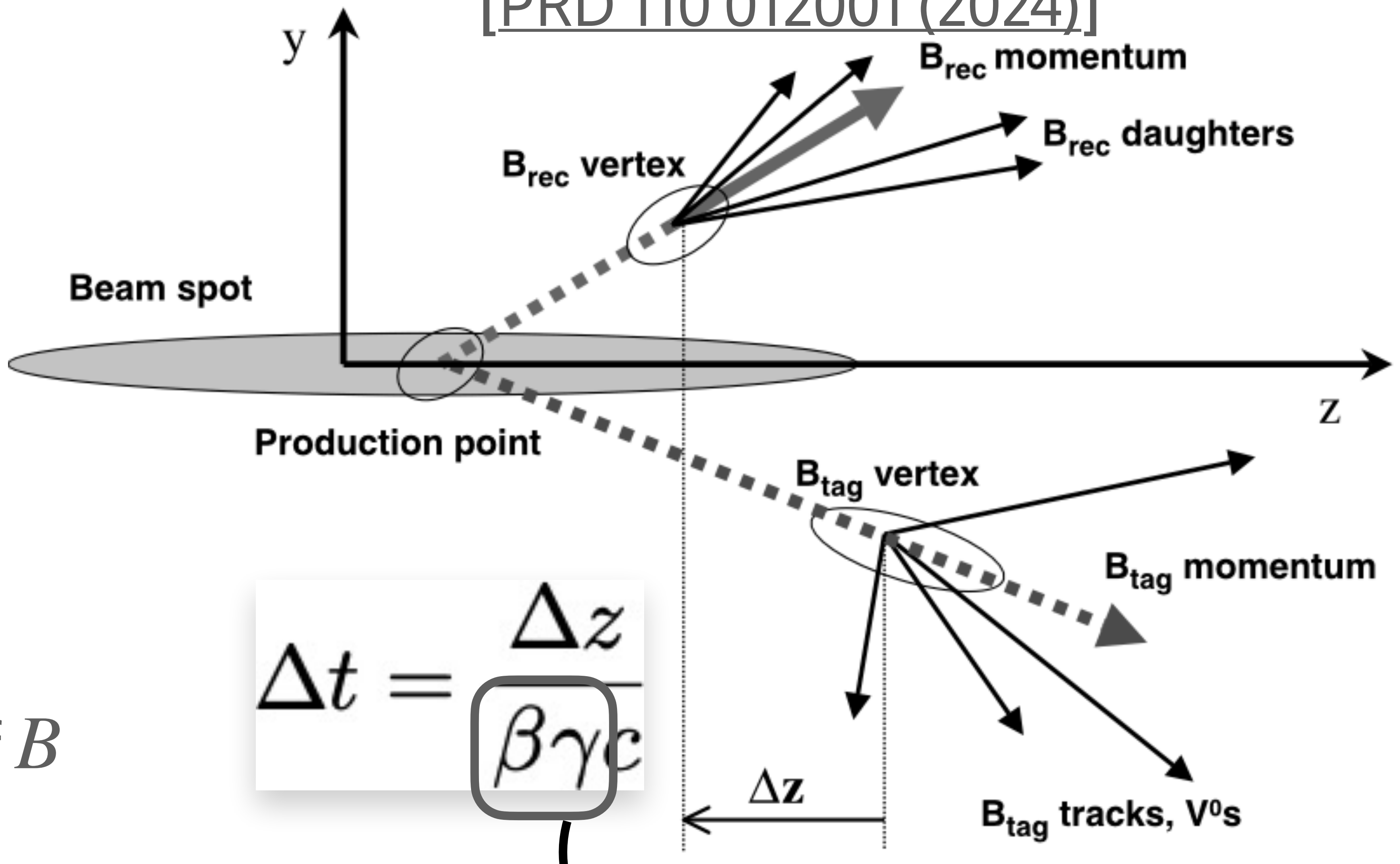
$e^+e^- \to q\bar{q}, q = u, d, s, c$

Flavor Tagging

CP analyses

[Eur. Phys. J.C 82, 283 (2022)]

[PRD 110 012001 (2024)]



$$\Delta t = \frac{\Delta z}{\beta\gamma c}$$

Boost = 0.29

Aid to missing energy B decays

Full Event Interpretation (FEI)

[Comput Softw Big Sci 3, 6 (2019)]

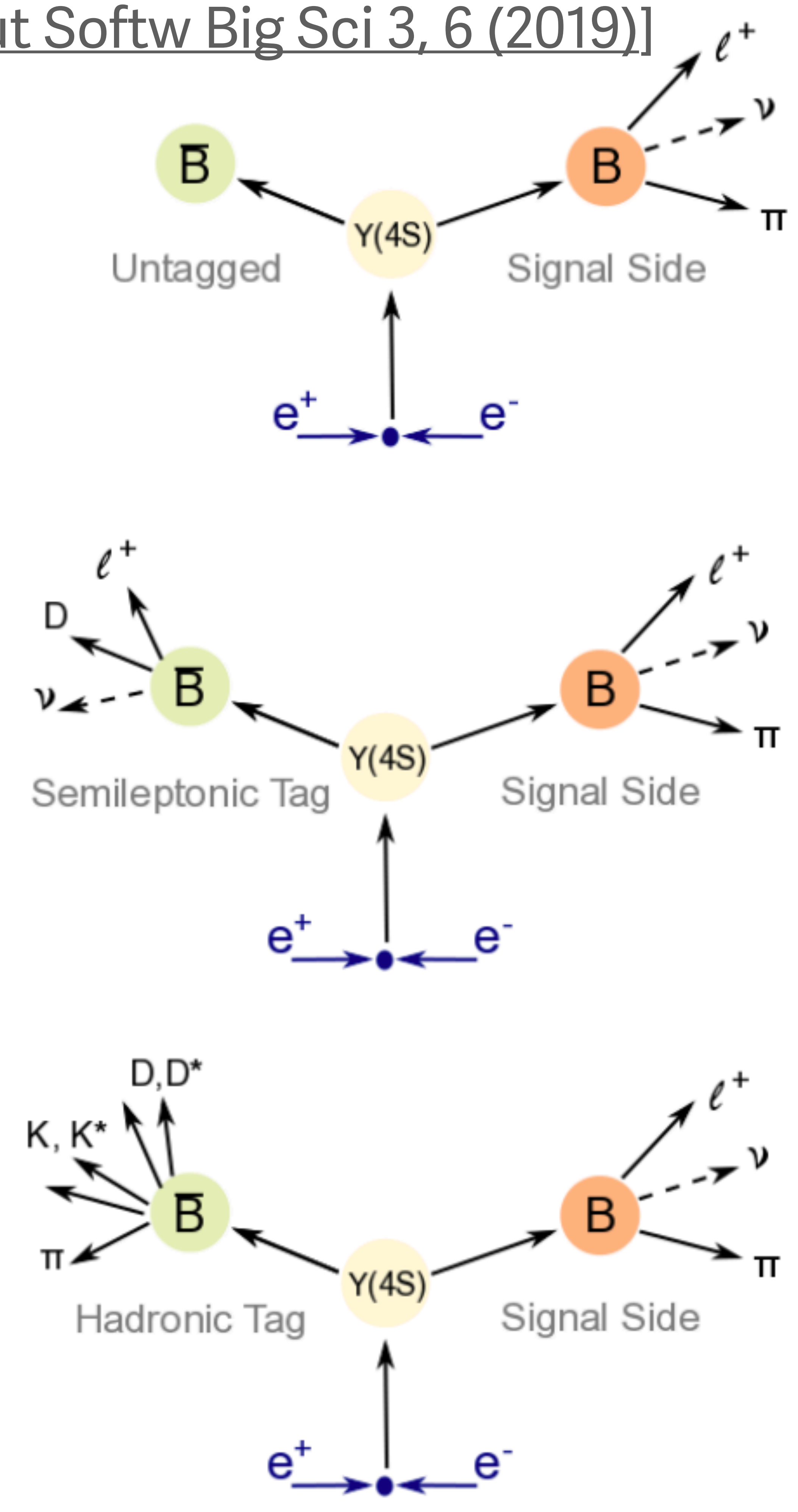


Image from L. Cao

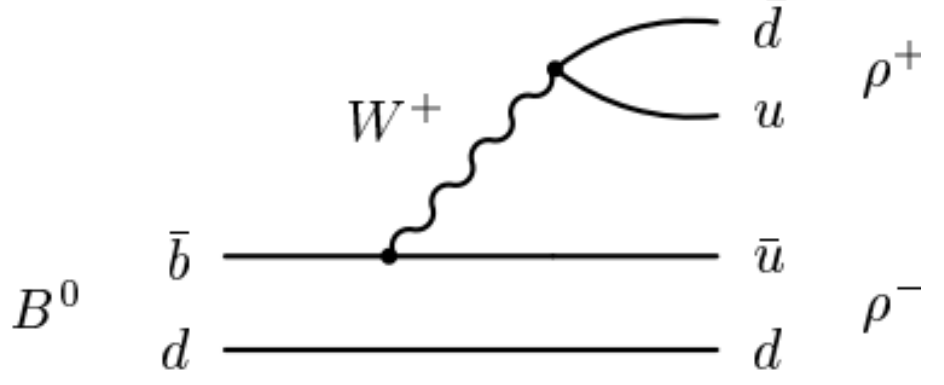
Hadronic B decays at Belle and Belle II

- $B^0 \to \rho^+\rho^-$
- $B^0 \to \bar{\Lambda}^0\Omega_c^{(*)0}$

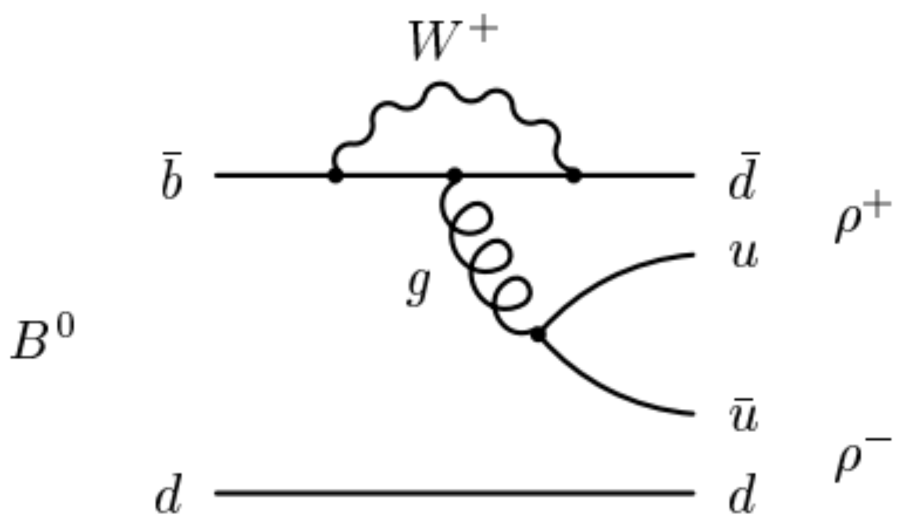
Prologue: $B^0 \to \rho^+\rho^-$

Theoretical motivation

- $B^0 \to \rho^+\rho^-$ provides stringent constraint on ϕ_2 due to small contribution from the “loop” amplitude
- Angle $\phi_2/\alpha = \arg(-\mathrm{V_{td}V^*_{tb}/V_{ud}V^*_{ub}})$ is the least known angle of the UT



Leading amplitude



Sub-leading amp. (small cont.)

Probability distribution

Mixing-induced CPV param.

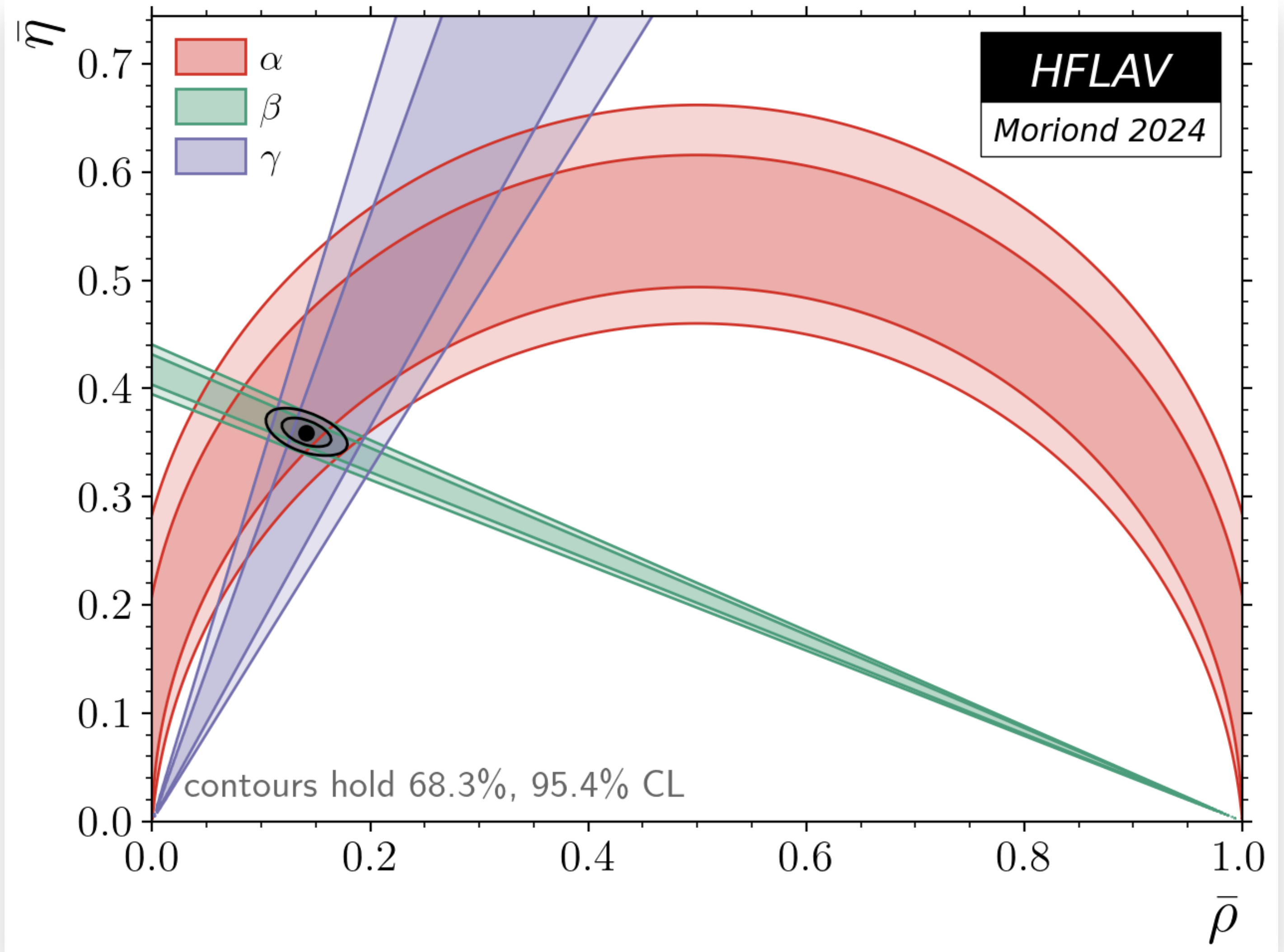
$$P(\Delta t, q) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\Big\{1 + q\big[S\sin(\Delta m_d \Delta t) - C\cos(\Delta m_d \Delta t)\big]\Big\},$$

Direct CPV param.

Helicity angle distribution

Longitudinal polarisation fraction

$$\frac{1}{\Gamma}\frac{d^2\Gamma}{d\cos\theta_{\rho^+}\, d\cos\theta_{\rho^-}} = \frac{9}{4}\left[\frac{1}{4}(1-f_L)\sin^2\theta_{\rho^+}\sin^2\theta_{\rho^-} + f_L\cos^2\theta_{\rho^+}\cos^2\theta_{\rho^-}\right],$$



$\phi_1 \equiv \beta = (22.6^{+0.5}_{-0.4})^\circ$ $\phi_3 \equiv \gamma = (66.4^{+2.8}_{-3.0})^\circ$ $\phi_2 \equiv \alpha = (84.1^{+4.5}_{-3.8})^\circ$

Decresing order of precision

Experiment

- Measurements dominated by BaBar and Belle (BF, CP, polarisation)
- Challenging due to presence of 4 photons in the final state; peaking bkgs and combinatorics

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

New

arXiv:2412.19624 | Submitted to Phys. Rev. D

Goal: Branching fraction (BF), polarisation, CP asymmetry, ϕ_2 measurement

STEP I: Reconstruction ($B^0 \to \rho^+[\to \pi^+\pi^0[\to \gamma\gamma]]\ \rho^-$)

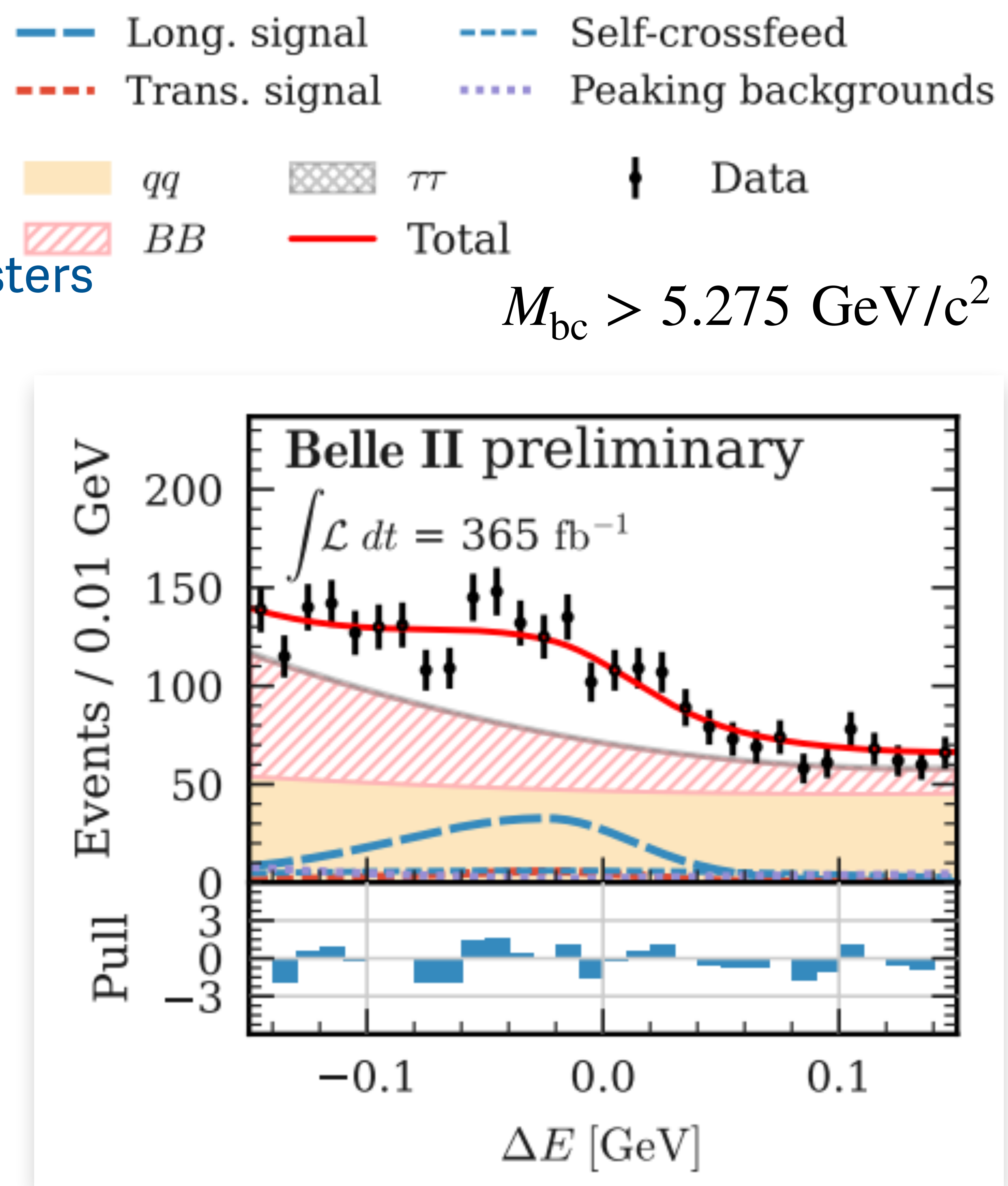
- Boosted Decision Tree (BDT) based separation of photons from hadronic clusters
- Signals are discriminated from backgrounds via $M_{\rm bc}$ and ΔE

$$M_{\rm bc} = \sqrt{E^{*2}_{\rm beam}/c^4 - p^{*2}_B/c^2} \qquad \Delta E = E^*_B - E^*_{\rm beam}$$

- $B_{\rm tag}$ flavor is identified using a **GNN-based flavor tagger** [PRD 110 012001 (2024)]
  - **18% improvement** over category-based Belle II FT algorithm [Eur. Phys. J.C 82, 283 (2022)]

Backgrounds

- Continuum backgrounds are suppressed using a TabNet classifier
- Other irreducible backgrounds: combinatorial and peaking $B\bar{B}$, $\tau^+\tau^-$, and signal "cross-feeds" are modelled with PDFs



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

New

arXiv:2412.19624 | Submitted to Phys. Rev. D

Belle II

STEP II: Signal extraction fit (**2 stage fit**)

- Stage 1: Extended ML fit to 6 obs: $\Delta E, m_{\pi^\pm\pi^0}, T_C, \cos\theta_{\rho^\pm}$
  - Extract $\mathscr{B}, f_L$ (longitudinal polarisation)
- Stage 2: Extended ML fit to 3 obs: $\Delta t, q, r$ → tag quality; → Flavor $B(\bar{B}) \equiv 1(-1)$
  - Extract $S,\ C$

Results

(Preliminary)

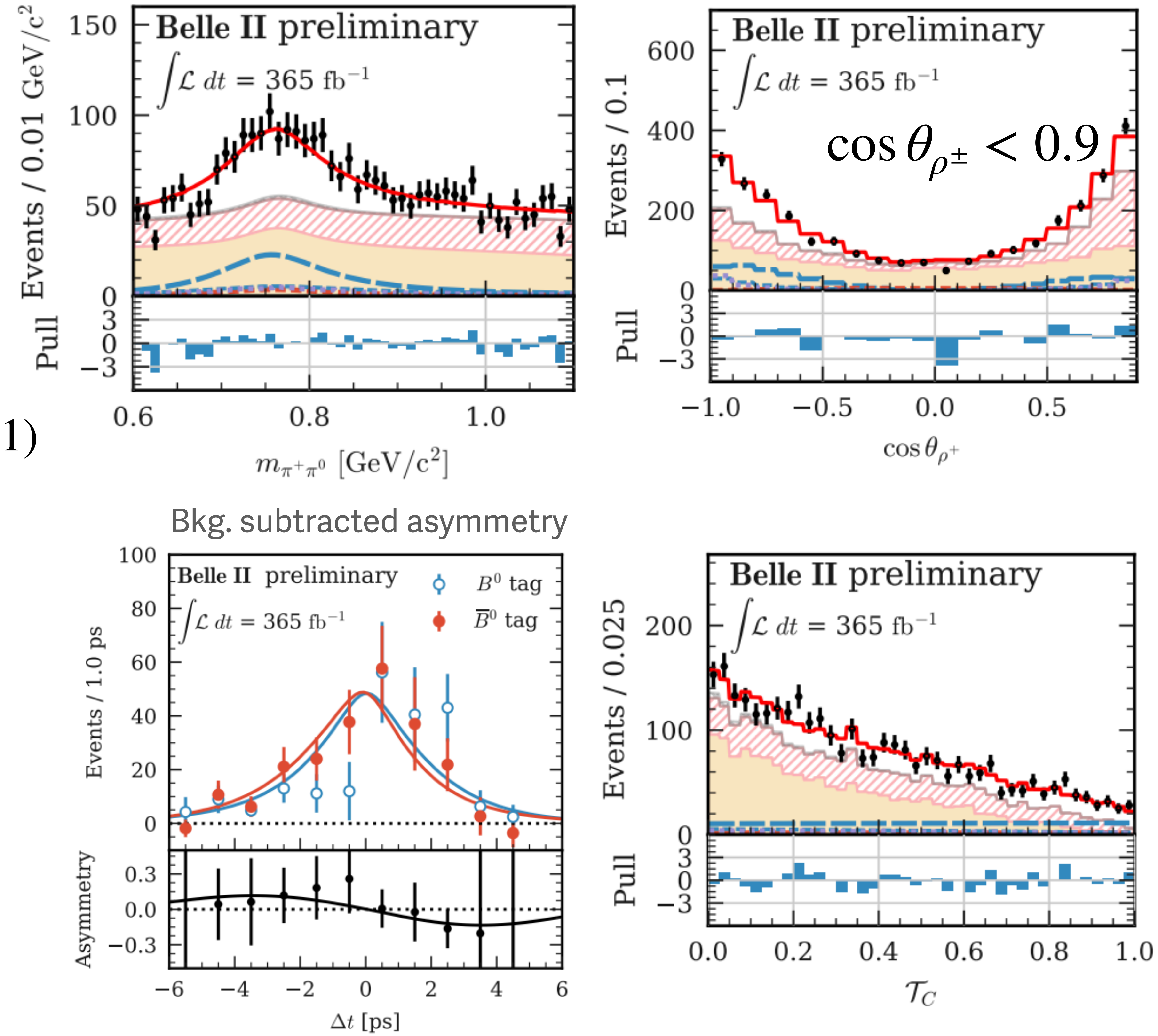
$$\mathscr{B}(B^0 \to \rho^+\rho^-) = (2.88^{+0.23}_{-0.22}{}^{+0.29}_{-0.27}) \times 10^{-5}$$

$$f_L = 0.921^{+0.024}_{-0.025}{}^{+0.017}_{-0.015}$$

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

$$C = -0.02 \pm 0.12 \pm 0.05$$

First uncertainty is statistical, second is systematics



Good agreement with previous BaBar (2007) and Belle (2016) expt. with equivalent BaBar and ~ 50% of Belle equivalent luminosity !

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

New

arXiv:2412.19624 | Submitted to Phys. Rev. D

STEP III: Constraining ϕ_2

$$\frac{1}{\sqrt{2}}A_{+-} + A_{00} = A_{+0},$$
$$\frac{1}{\sqrt{2}}\bar{A}_{+-} + \bar{A}_{00} = \bar{A}_{-0},$$

- Perform isospin analysis based on longitudinal amplitudes, A_{ij}
- Constrain using **this** measurement + **World Averages** (BaBar, Belle, LHCb)
- Correct $\mathcal{B}$ due to inclusion of f_{+-}/f_{00} systematics HFLAV24 (NEW)

  - Inclusion shifts the ϕ_2 value by $-0.4°$

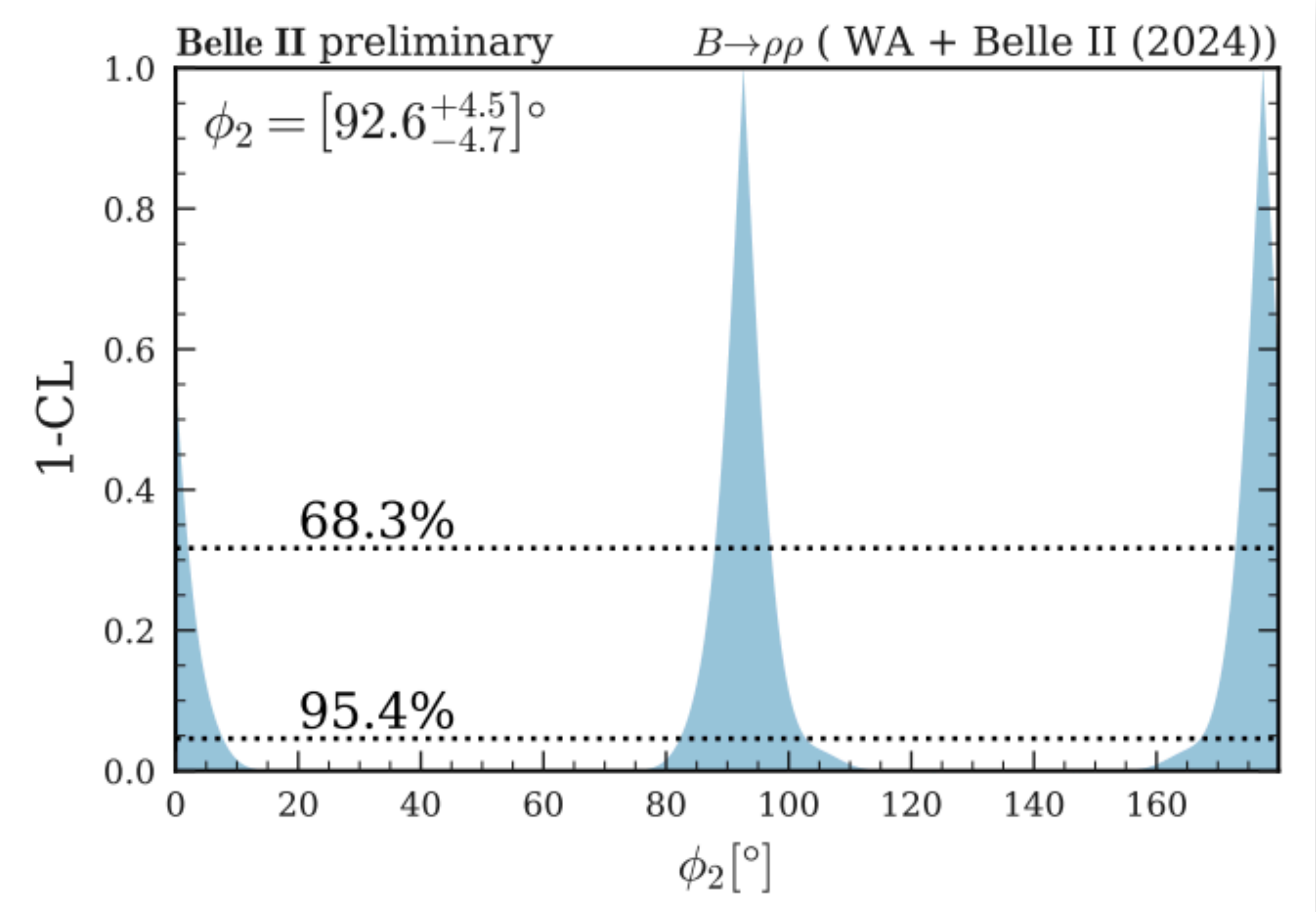
Result (from this measurement) (Preliminary)

$$\phi_2 = (\ 91.5\ ^{+4.8}_{-5.2}\ )°$$

$$\Delta\phi_2 = (\ 2.4\ ^{+4.2}_{-3.8}\ )°$$

Agrees with WA, HFLAV24

- Belle II result improves the ϕ_2 value by ~8%
- Dominant systematics (this measurement) from S [backup]



Second solution of ϕ_2 excluded by ϕ_1 and ϕ_3 measurements

Prologue: $B^0 \to \bar{\Lambda}^0 \Omega_c^{(*)0}$

Theoretical motivation

- Probe low-energy mechanism for baryon number violation [Phys. Rev. D 96, 075009 (2017)]

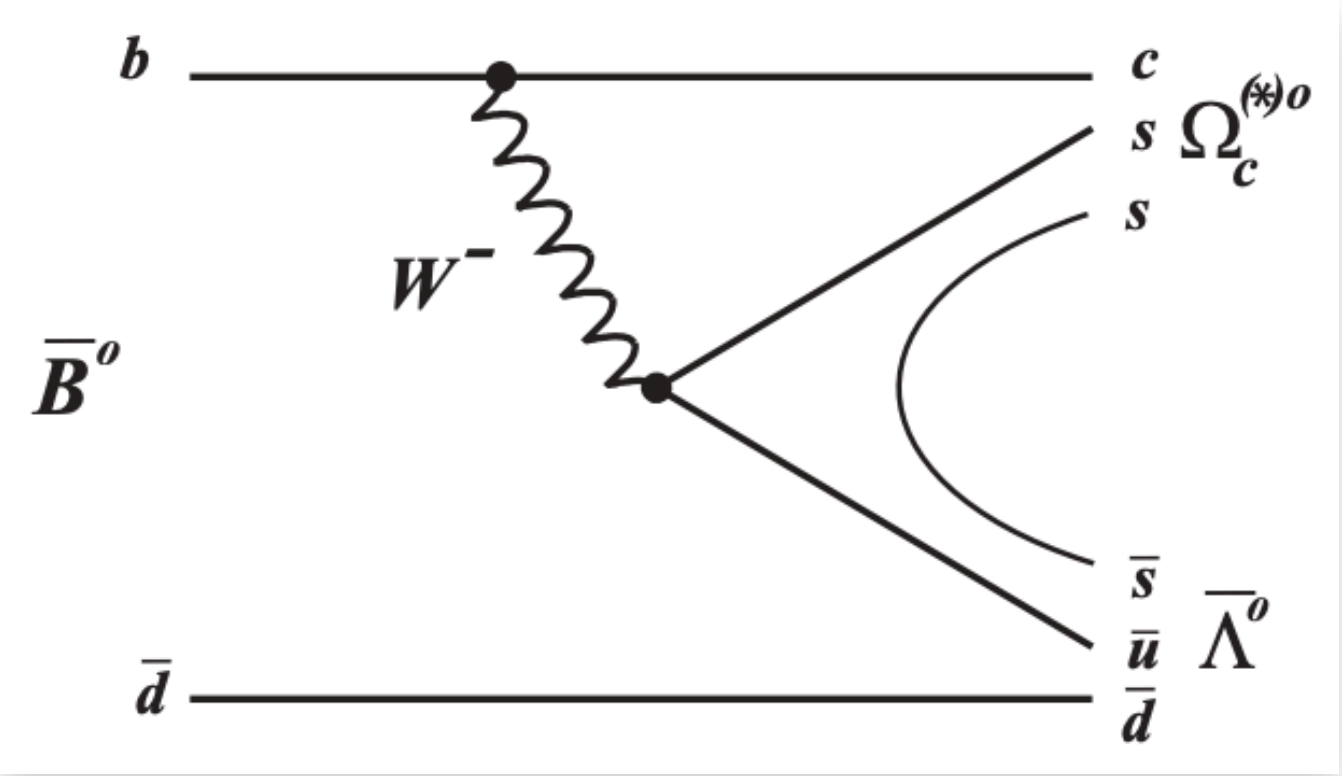
$$\bar{B}^0 \to \bar{\Lambda}^0 \Omega_c^0, \bar{B}^0 \to \bar{\Lambda}^0 \bar{\Omega}_c^0$$

Cabibbo suppressed SM decay

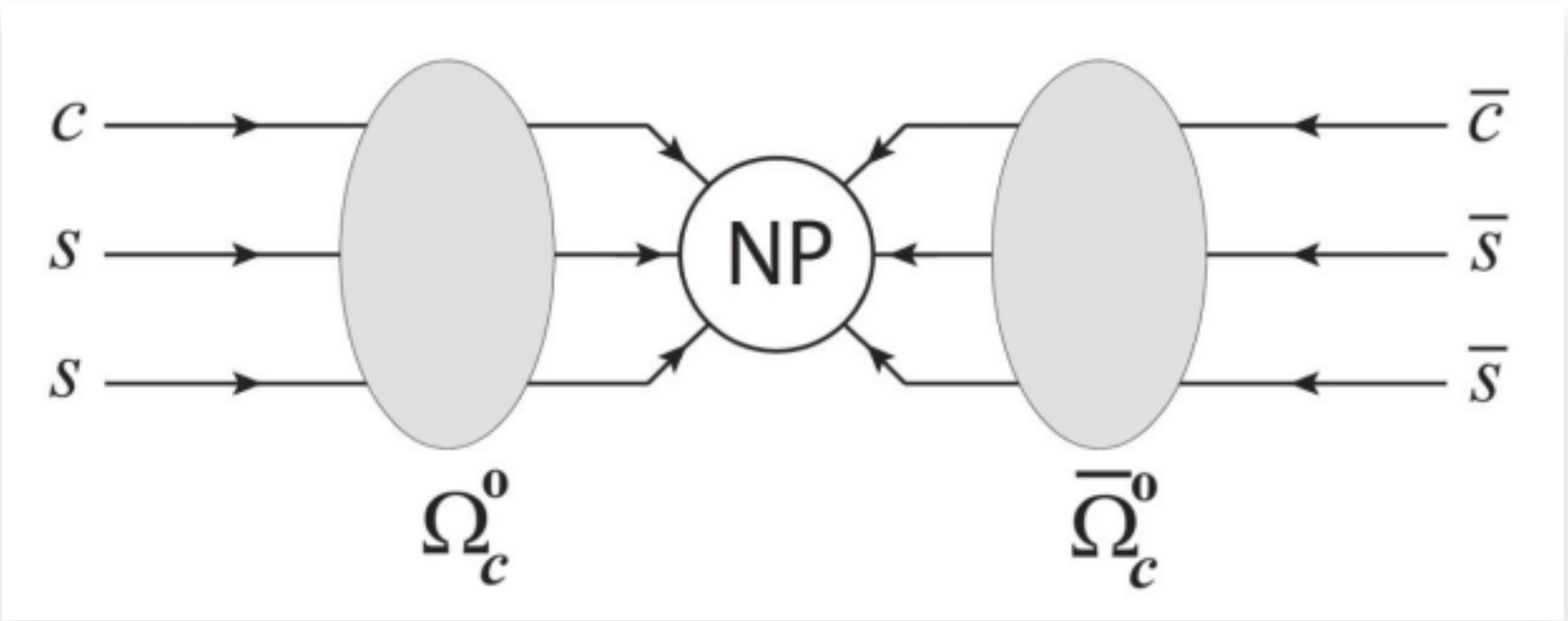
Beyond SM decay

- Poorly understood due to large hadronic uncertainties

$\bar{B}^0 \to \bar{\Lambda}^0 \Omega_c^{(*)0}$



$\Omega_c^0 \leftrightarrow \bar{\Omega}_c^0$



Experiment

- No previous experimental measurements exist
- Searched for the first time using Belle dataset
- Consider two Ω_c^0 states: Ω_c^0 and $\Omega_c(2700)^0$, collectively referred to as $\Omega_c^{(*)0}$

$B^0 \to \bar{\Lambda}^0 \Omega_c^{(*)0}$

New

Phys. Rev. D 110, L031102 (2024)

Goal: Search for the decays $\bar{B}^0 \to \bar{\Lambda}^0 \Omega_c^0$ and $\bar{B}^0 \to \bar{\Lambda}^0 \bar{\Omega}_c^0$

Dataset: $711\ \text{fb}^{-1}$ of Belle data collected at $\Upsilon(4S)$ resonance

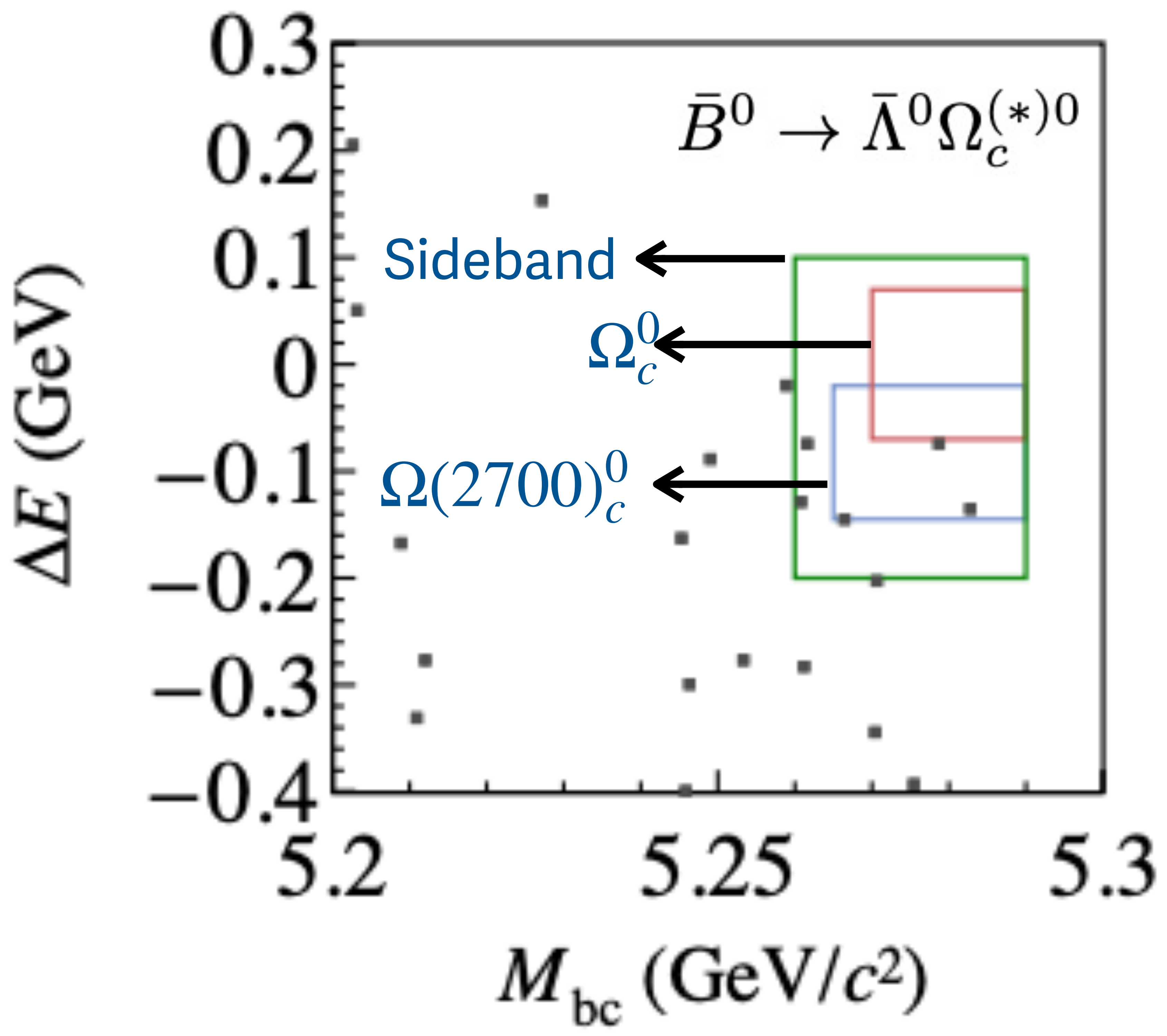
STEP I: Reconstruction

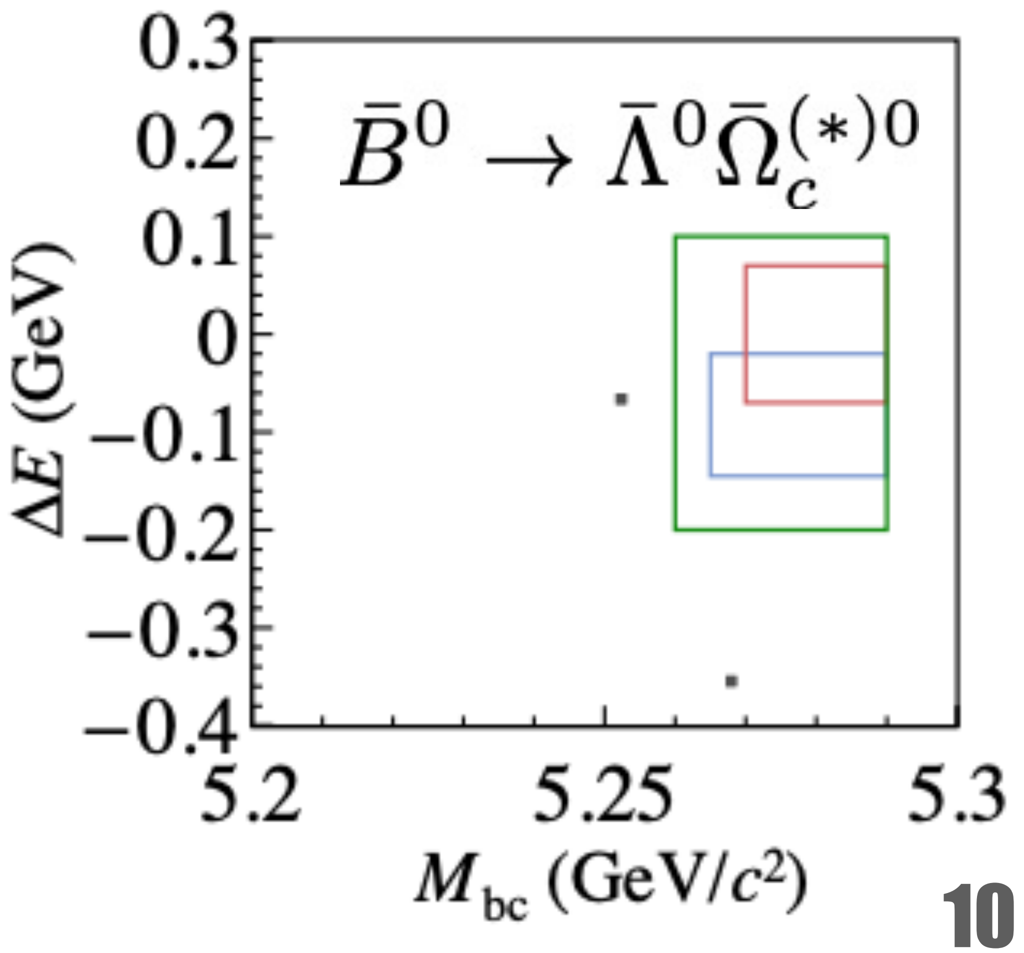
- Signal B^0's are reconstructed from:

  $\Lambda^0 \to p\pi^-, \Omega^- \to K^-\Lambda^0, \Omega_c^0 \to \pi^+\Omega^-, \Omega(2770)_c^0 \to \Omega_c^0\gamma$ (partially reco.)

- Two signal categories: $\bar{\Lambda}^0\Omega_c^{(*)0}, \bar{\Lambda}^0\bar{\Omega}_c^{(*)0}$
- PID selections, mass / vertex-constraint fits, selection on the decay lengths performed to reduce combinatorics
- Signals are discriminated from the backgrounds using the kinematic variables: M_{bc}, ΔE

$$M_{bc} = \sqrt{E_{beam}^{*2}/c^4 - p_B^{*2}/c^2} \qquad \Delta E = E_B^* - E_{beam}^*$$





$B^0 \to \bar{\Lambda}^0 \Omega_c^{(*)0}$

New

Phys. Rev. D 110, L031102 (2024)

STEP II: Signal extraction

- Use counting method due to low background statistics
- Simulations confer that events outside the signal (blinded) region are dominated by $q\bar{q}$ and non-signal $B\bar{B}$ events

Numbers of events	Total	Blinded region	$\bar{\Lambda}^0\Omega_c^0$ signal region	$\bar{\Lambda}^0\Omega_c(2770)^0$ signal region
$\bar{\Lambda}^0\Omega_c^0$ data	21	5	0	3
Background	N/A	1.6 ± 0.7	0.44 ± 0.45	0.44 ± 0.45
$\bar{\Lambda}^0\bar{\Omega}_c^0$ data	2	0	0	0
Background	N/A	0.18 ± 0.17	0.00 ± 0.12	0.12 ± 0.15

Results

First upper limits on 2-body BNV decays

Quantity $(\times \mathcal{B}(\Omega_c^0 \to \Omega^-\pi^+))$	Upper limit (at 95% CL)
$\mathcal{B}(B \to \bar{\Lambda}^0\Omega_c^0)$	9.7×10^{-8}
$\mathcal{B}(B \to \bar{\Lambda}^0\Omega_c(2770)^0)$	31.2×10^{-8}
$\mathcal{B}(B \to \bar{\Lambda}^0\bar{\Omega}_c^0)$	9.5×10^{-8}
$\mathcal{B}(B \to \bar{\Lambda}^0\bar{\Omega}_c(2770)^0)$	10.0×10^{-8}

B flavor blind measurements

Source	Uncertainty (%)
Track reconstruction (overall)	2.9
π^+ PID (for $\Omega_c^0 \to \pi^+\Omega^-$)	0.8
K^- PID (for $\Omega^- \to K^-\Lambda^0$)	1.4
p PID (for Λ^0 decays)	2×1.0
Decay length (Ω^-)	2.0
Reconstructed masses	4×0.5
Vertex fits (χ^2)	1.5
M_{bc} and ΔE	0.5
$\mathcal{B}(\Omega^- \to \Lambda^0 K^-)$	1.0
$\mathcal{B}(\Lambda^0 \to p\pi^-)$	2×0.7
$N_{B^0\bar{B}^0}$	2.9
Detector charge asymmetry	0.8
Polarization of baryons	0.5
MC statistics	0.7
Overall (σ_r)	6.2

Missing energies leptonic B decays at Belle II

- $B^+ \to \tau^+ \nu_\tau$

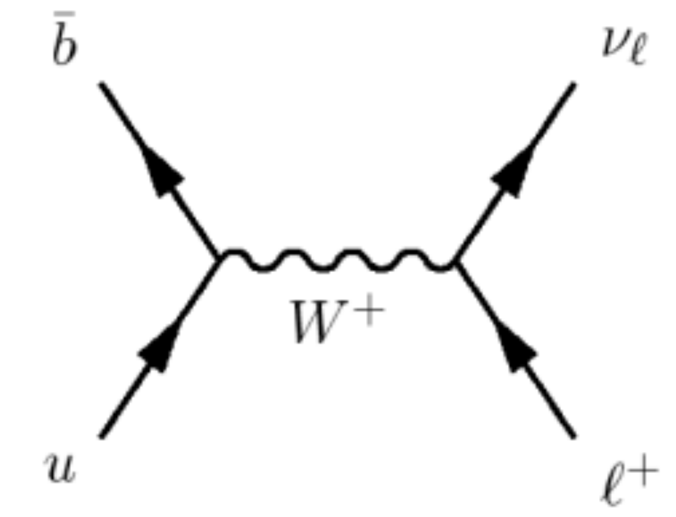
Prologue: $B^+ \to \tau^+ \nu$

Theory

- Precise BF value is important to check consistency with SM predictions / constrain new physics

$$\mathscr{B}(B \to \tau\nu) > \mathscr{B}(B \to \mu\nu) > \mathscr{B}(B \to e\nu)$$

BF decreases with decrease in m_ℓ and increase in helicity suppression



SM Feynman diagram

- Potential modes to precisely measure $|V_{ub}|$

$$\mathcal{B}(B^+ \to \ell^+ \nu_\ell) = \frac{G_F^2\, m_B\, m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2\, |V_{ub}|^2\, \tau_B$$

encodes $b \to u$ annihilation info. (theory input)

Experiment

- Challenging (particularly, τ mode) due to undetected neutrinos in the final state
- At present, the measurements are statistically limited

Experiment	Tag	$\mathcal{B}(10^{-4})$
Belle	Hadronic	$0.72^{+0.27}_{-0.25} \pm 0.11$
BABAR	Hadronic	$1.83^{+0.53}_{-0.49} \pm 0.24$
Belle	Semileptonic	$1.25 \pm 0.28 \pm 0.27$
BABAR	Semileptonic	$1.8 \pm 0.8 \pm 0.2$
PDG		1.09 ± 0.24

$B^+ \to \tau^+ \nu$

New arXiv: 2502.04885 | Submitted to Phys. Rev. D

Goal: BF measurement using hadronic tagging (*First from Belle II*)

STEP I: Reconstruction

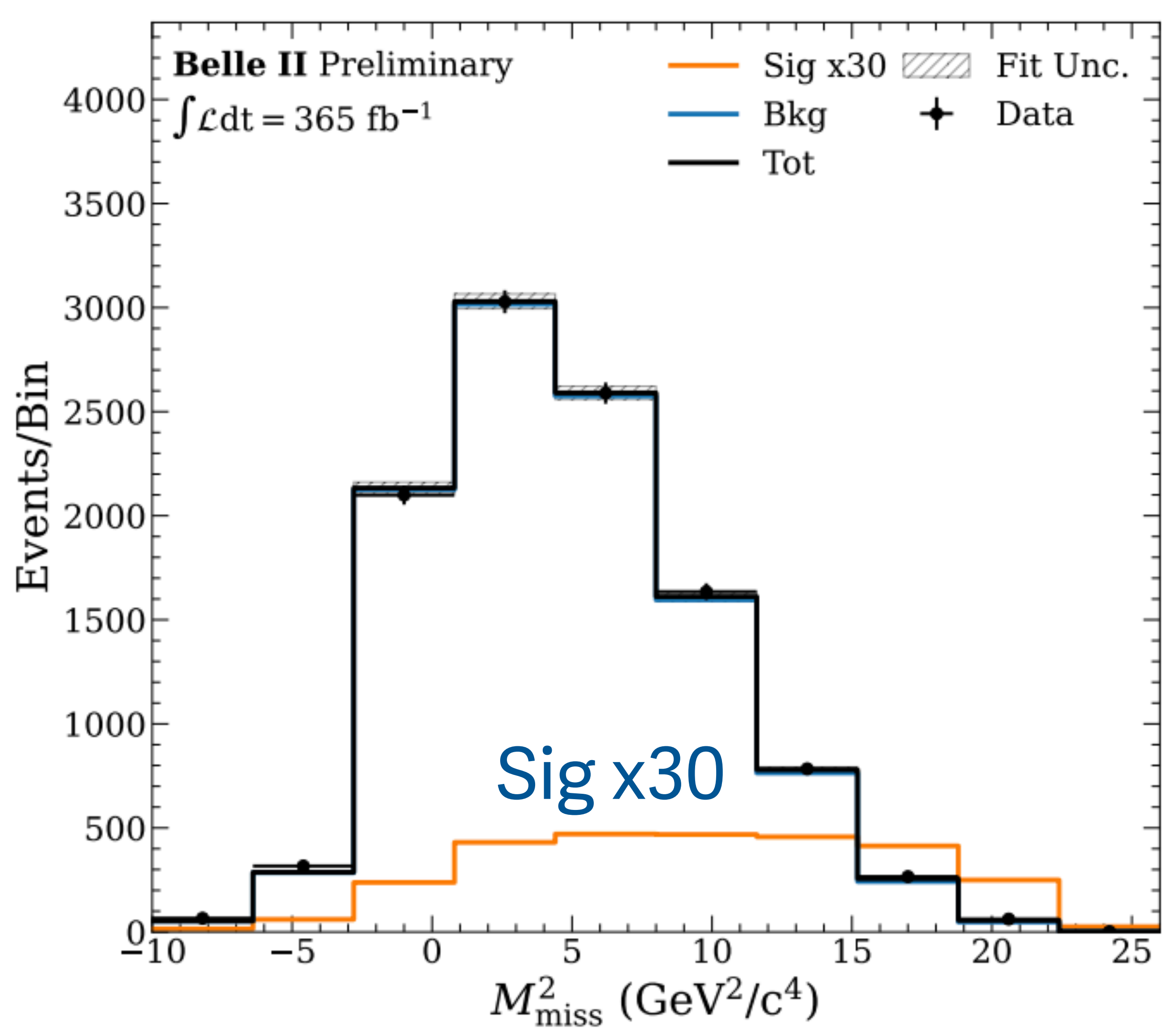
- Use hadronic FEI to reconstruct the companion B, the B_{tag}
- Reconstruct B_{sig} from the remaining tracks and clusters
- Use both leptonic (e, μ) and hadronic channels (π, ρ) of τ's (~70% BF coverage)
- Use two most discriminating variables, M^2_{miss}, $E^{\mathrm{extra}}_{\mathrm{ECL}}$:

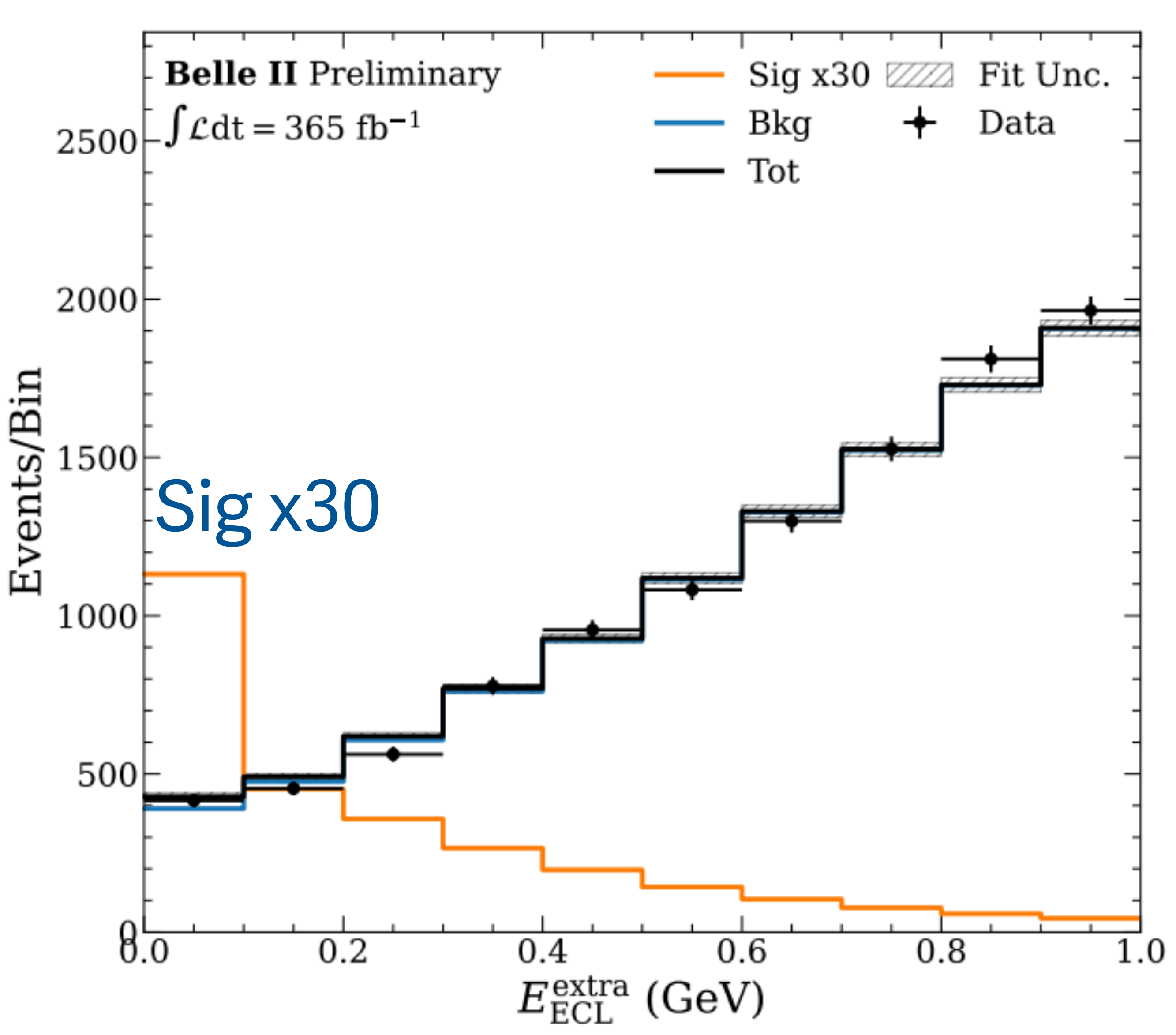
$$M^2_{\mathrm{miss}} = (p^*_{\mathrm{beam}} - p^*_{\mathrm{tag}} - p^*_{\mathrm{sig}} - p^*_{\mathrm{ROE}})^2$$

$$E^{\mathrm{extra}}_{\mathrm{ECL}} \equiv \text{Total residual energy from neutral clusters}\,\dagger$$

† use of BDTs to clean the neutral clusters $\notin B_{\mathrm{tag}}, B_{\mathrm{sig}}$

Signal signature: high M^2_{miss} and low $E^{\mathrm{extra}}_{\mathrm{ECL}}$





$B^+ \to \tau^+\nu$

New

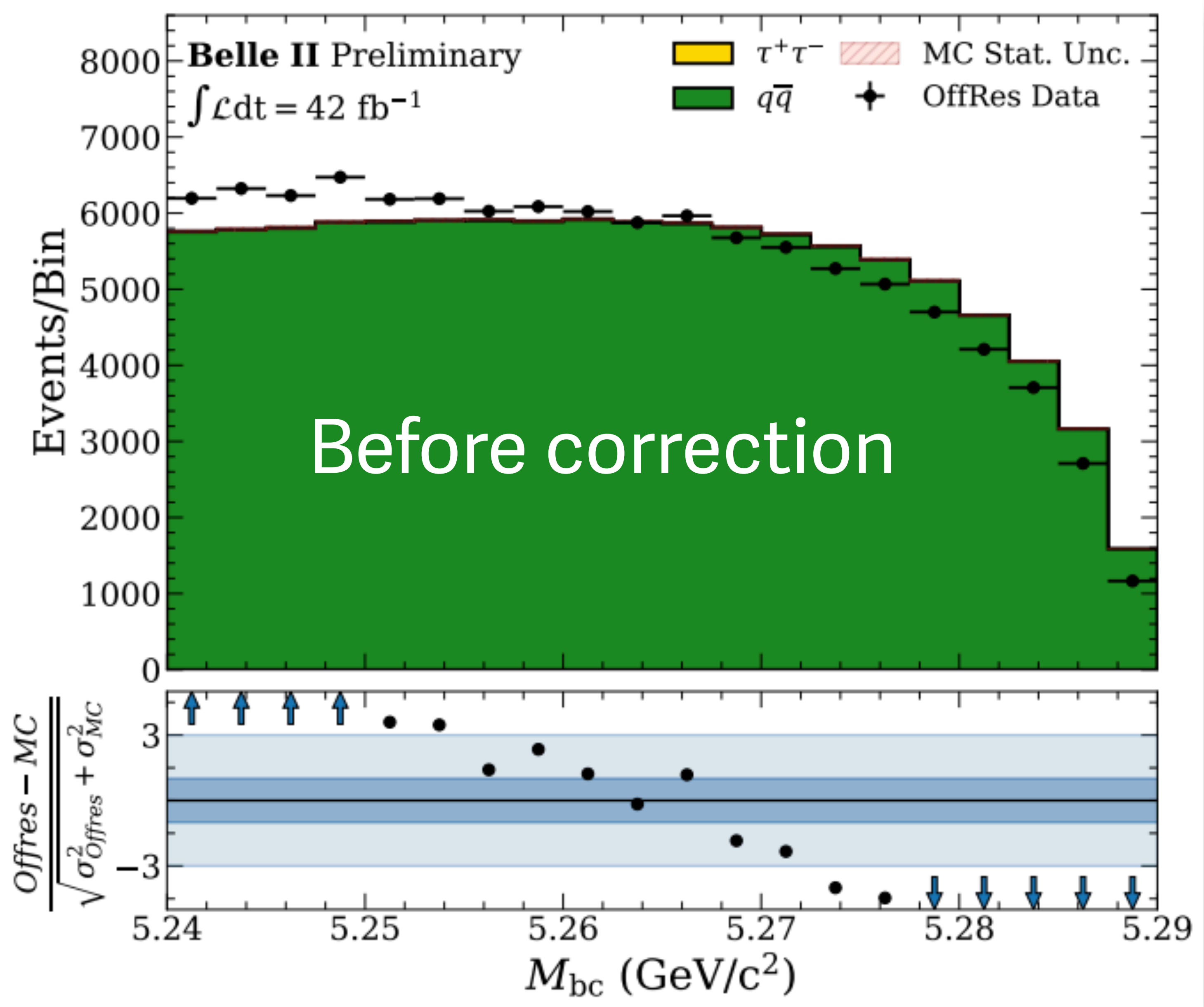
arXiv: 2502.04885 | Submitted to Phys. Rev. D

Belle II

STEP II: Background suppression

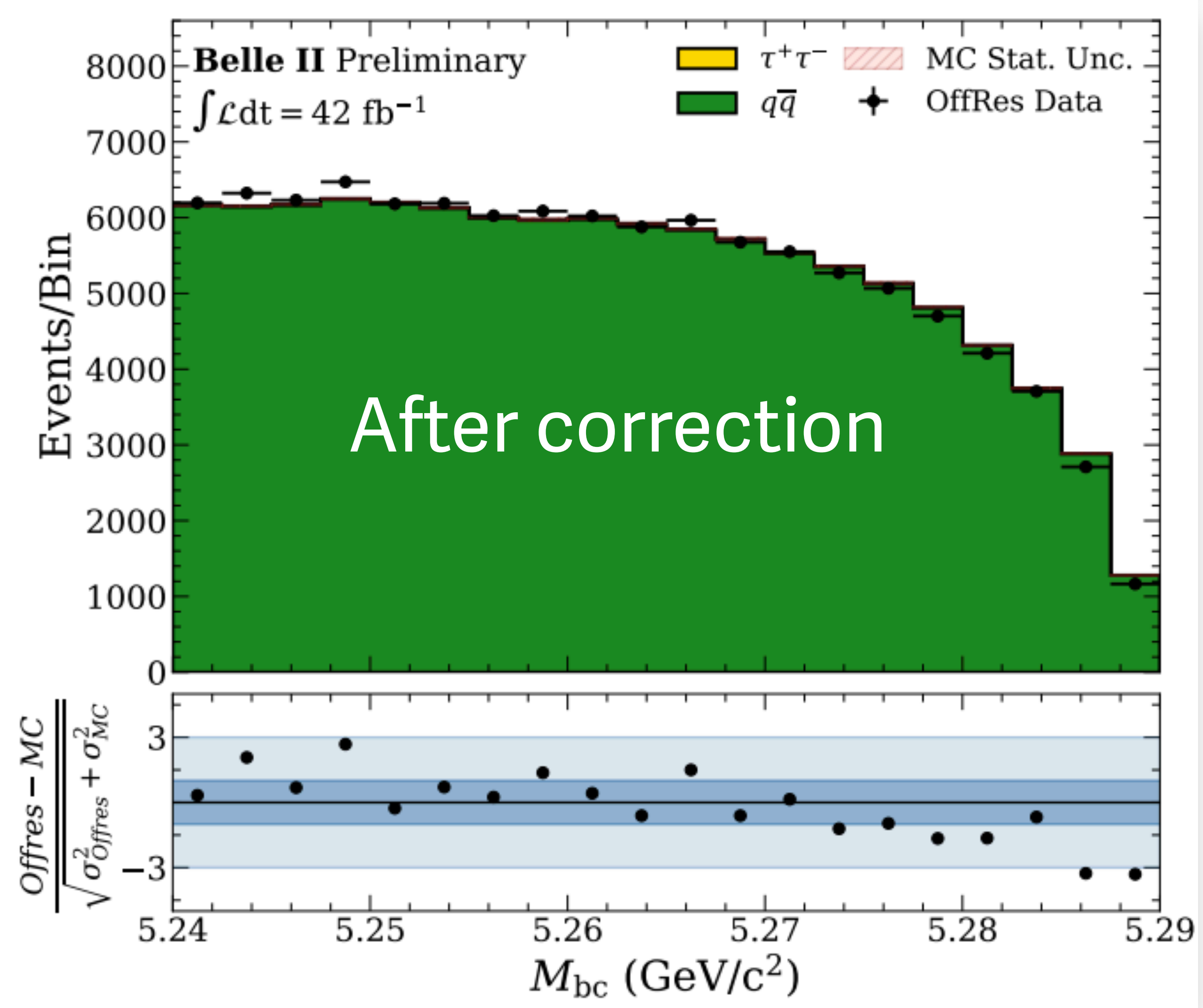
$\mathcal{L}_{\text{intg}}^{\text{OffRes}} = 42\ \text{fb}^{-1}$

- 2-stage BDTs
  - Continuum backgrounds ($e^+e^- \to q\bar{q}/\tau\bar{\tau}$) (dominant)
  - Non-signal $B\bar{B}$ backgrounds



STEP III: Calibration and validation

- Calibration:
  - FEI efficiency correction using data-driven methods (off-resonance data)
    - 2 control channels: $B \to X\ell\nu, B \to D^{(*)}\pi^+$
  - Cluster multiplicity corrections between data - simulation
  - Additional corrections include: misID, photon eff., continuum re-weighting
- Validation:
  - Validated using $B^+ \to D^{*0}\ell^+\nu_\ell$ control mode



$B^+ \to \tau^+\nu$

New arXiv: 2502.04885 | Submitted to Phys. Rev. D

STEP IV: Signal extraction

- Simultaneous **binned** ML 2D fit to $M^2_{\text{miss}}, E^{\text{extra}}_{\text{ECL}}$

Results (Preliminary)

3σ significance

$$\mathcal{B}(B^+ \to \tau^+\nu) = (1.24 \pm 0.41 \pm 0.19) \times 10^{-4}$$

First uncertainty is statistical, second is systematics

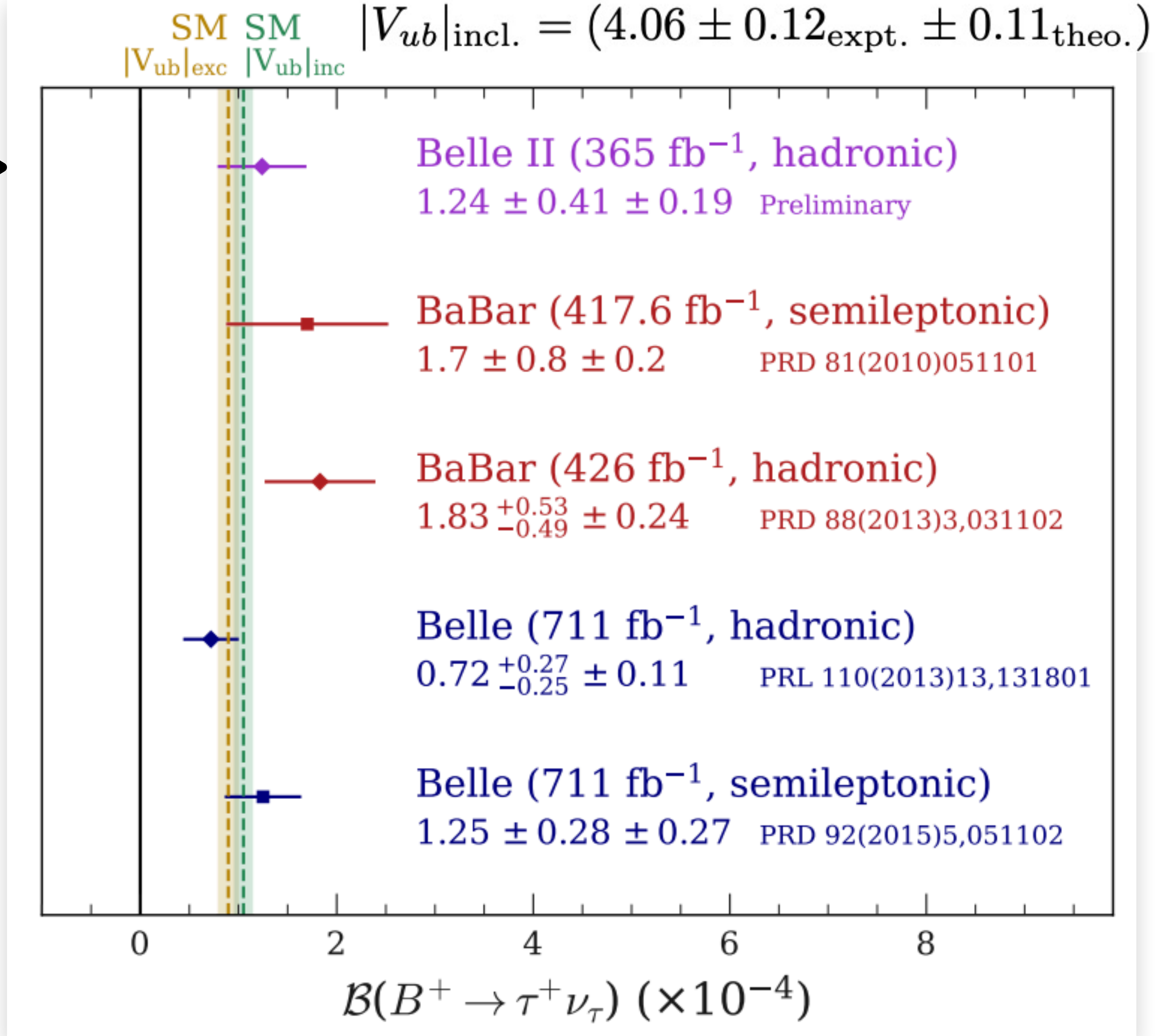
Assuming SM and $f_B = (190.0 \pm 1.3)$ MeV from FLAG24

$$|V_{ub}|_{B^+\to\tau^+\nu} = (4.41^{+0.74}_{-0.89}) \times 10^{-3}$$

- Consistent with world average and SM predictions
- Dominant systematics from limited statistics of simulations [backup]

$|V_{ub}|_{\text{excl.}} = (3.75 \pm 0.6_{\text{expt.}} \pm 0.19_{\text{theo.}}) \times 10^{-3}$

$|V_{ub}|_{\text{incl.}} = (4.06 \pm 0.12_{\text{expt.}} \pm 0.11_{\text{theo.}}) \times 10^{-3}$



More precise than BaBar (had. tag), with eqivalent dataset

First had-tagged results from Belle II

Missing energies semi-leptonic decays at Belle II

- $R(D^{(*)})$ semi-leptonic tag
- Untagged $B \to D\ell\nu$ and $|V_{cb}|$

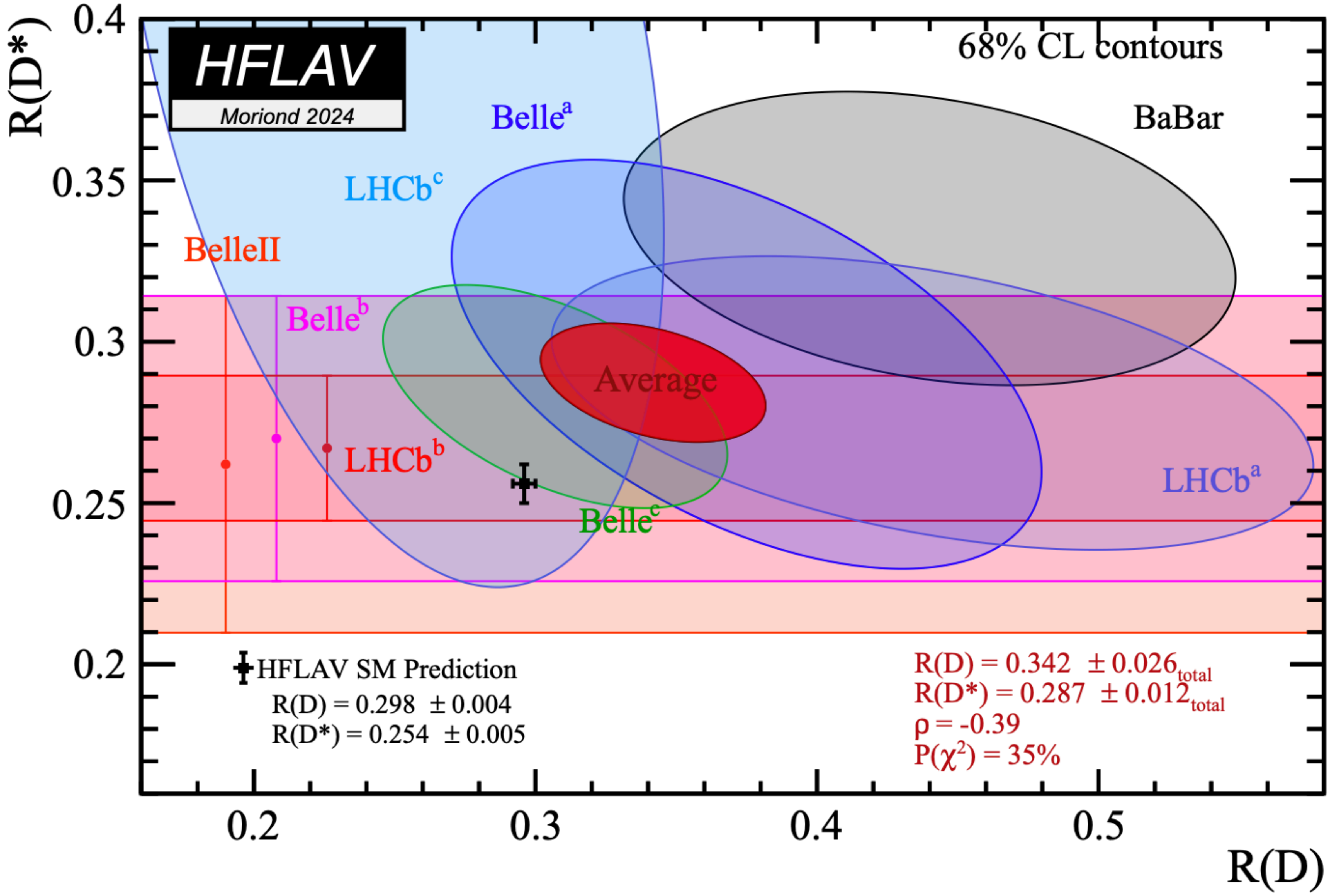
Prologue: $R(D^{(*)})$

Theory

- Lepton Flavor Universality (LFU) is an "accidental symmetry" within the SM broken only by charged lepton masses
- Highly sensitive to non-SM physics and can be probed by precise LFU ratios

$$\mathcal{R}(D^{(*)+}) = \frac{\mathcal{B}(\overline{B}^0 \to D^{(*)+}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\overline{B}^0 \to D^{(*)+}\ell^-\bar{\nu}_\ell)}$$

Combined deviation from SM stands at 3.3σ



Experiment

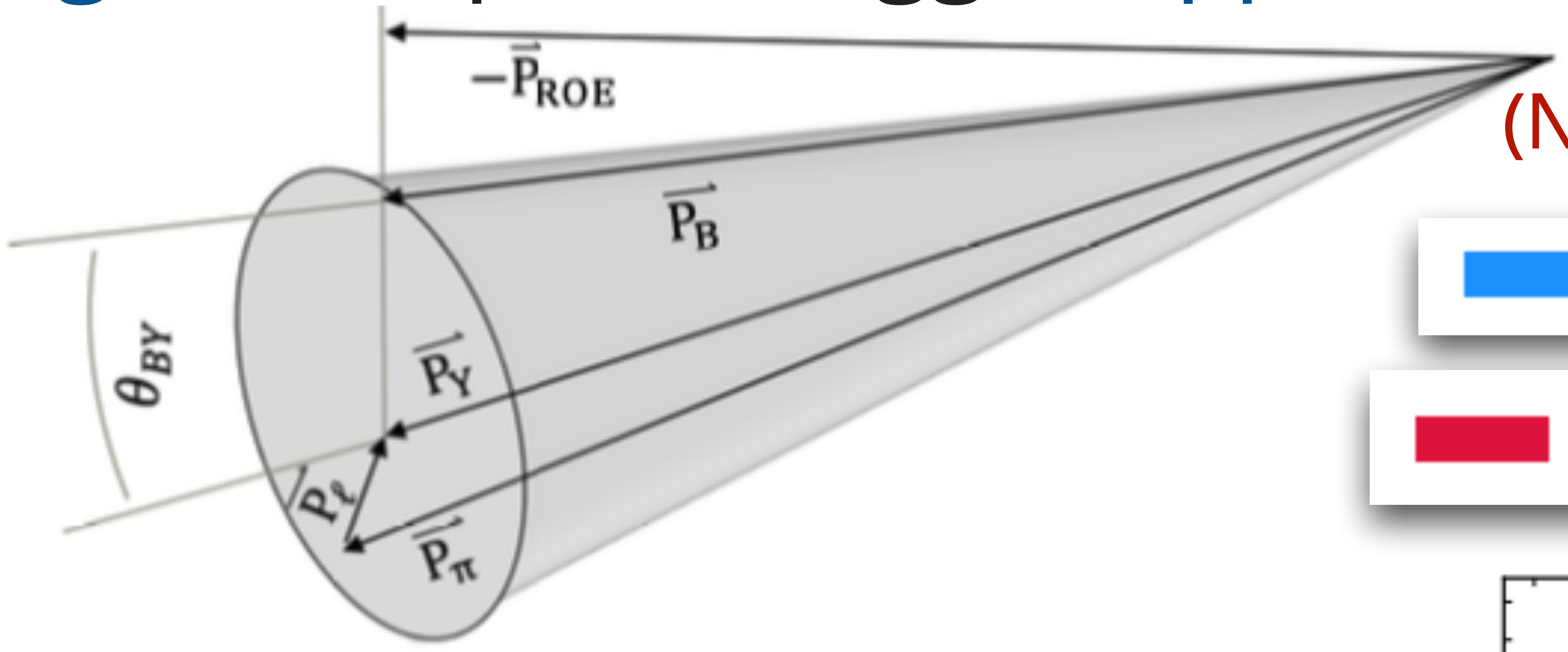
- Observe $\sim 3\sigma$ excess by BaBar, Belle (II), and LHCb experiments
- HFLAV24 average hints at potential new physics

$R(D^+)$ and $R(D^{*+})$

New

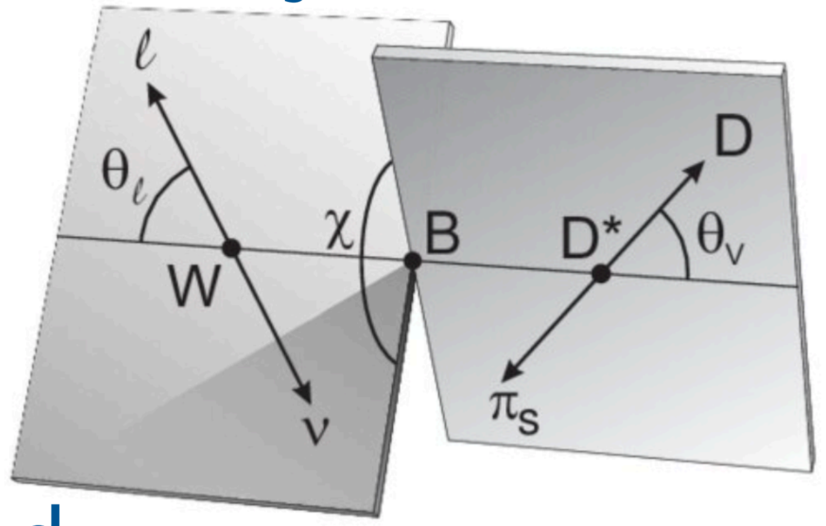
To be submitted to Phys. Rev. D

Goal: $R(D^+)$ and $R(D^{*+})$ measurement using semi-leptonic tagged approach *(First results)*



STEP I: Reconstruction

- Use semi-leptonic FEI to reconstruct the B_{tag}
- B_{sig} (B^0) is reconstructed from $D^{(*)}$, light leptons, and leptonic τ decays

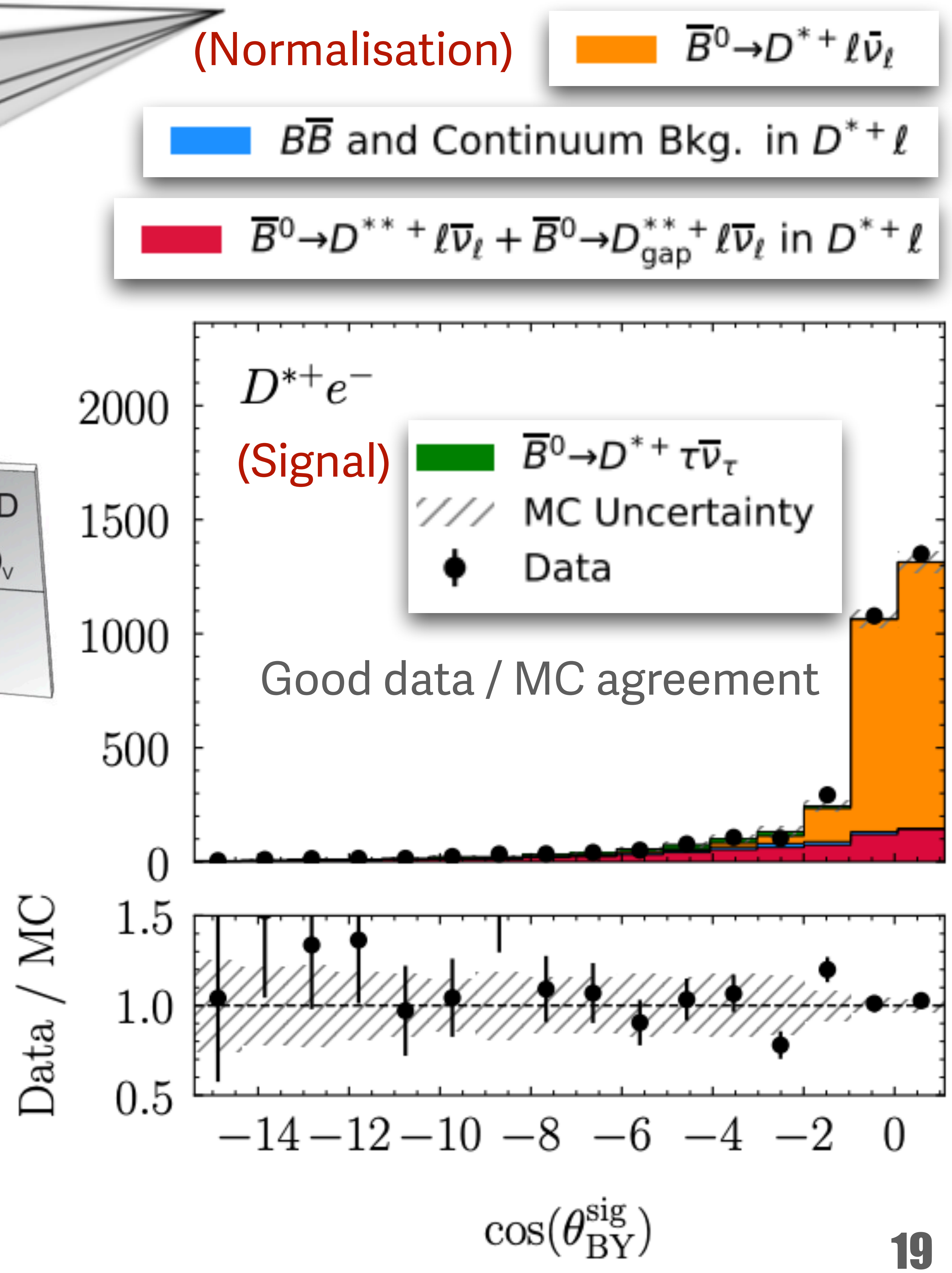


STEP II: MVA-based event classification

- BDT trained to classify semi-leptonic, semi-tauonic, background
- Input BDT variables: angular (2), momenta of ℓ, D (2), and E_{ECL}^{extra} (backup)

$$\cos\theta_{BY} = \frac{2E_{beam}E_Y - m_B^2 - m_Y^2}{2\,|\vec{p}_B|\,|\vec{p}_Y|}$$ (Most discriminating)

- Output scores: z_ℓ, z_τ, and z_{bkg}



$R(D^+)$ and $R(D^{*+})$

New — To be submitted to Phys. Rev. D

STEP III: Signal extraction

- 2D binned log-likelihood fit to z_τ and $z_{\text{diff}} = z_\ell - z_{\text{bkg}}$

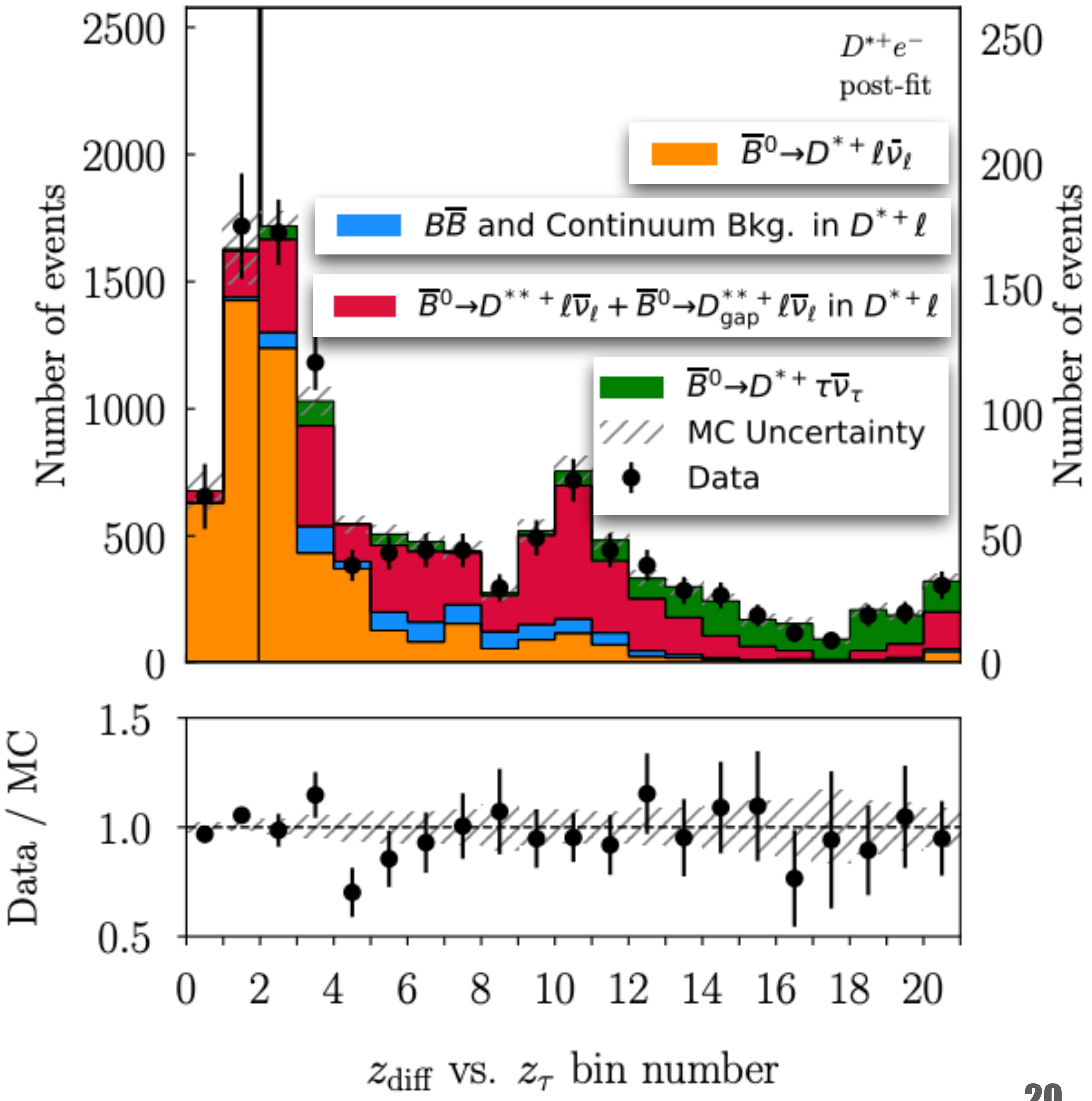
Signal yields across different fit categories

Sample	D^+e	$D^+\mu$	$D^{*+}e$	$D^{*+}\mu$
$\overline{B}^0 \to D^+\ell\bar{\nu}_\ell$	2519 ± 68	2233 ± 61		
$\overline{B}^0 \to D^{*+}\ell\bar{\nu}_\ell$	2486 ± 63	2323 ± 58	2344 ± 51	1961 ± 44
$\overline{B}^0 \to D^+\tau\bar{\nu}_\tau$	191 ± 41	155 ± 65		
$\overline{B}^0 \to D^{*+}\tau\nu$	106 ± 14	84 ± 11	155 ± 19	111 ± 14
$\overline{B} \to D^{**}\ell\bar{\nu}_\ell/\overline{B} \to D^{**}_{\text{gap}}\ell\bar{\nu}_\ell$	653 ± 112	586 ± 102	87 ± 55	75 ± 46
$B\overline{B}$ and Continuum Bkg.	2177 ± 145	1582 ± 149	611 ± 95	497 ± 83
Data	8219	6854	3241	2621

Stability checks agree with the nominal values [backup]

- Redetermine $R(D^{(*+)})$ using different sample splits: lepton flavor, charge, lepton polar angle, # tracks, $D^{(*+)}$ channels
- Simultaneous fit to account for correlations in common syst.

Preliminary



$\mathcal{R}(D^+)$ and $\mathcal{R}(D^{*+})$

New — To be submitted to Phys. Rev. D

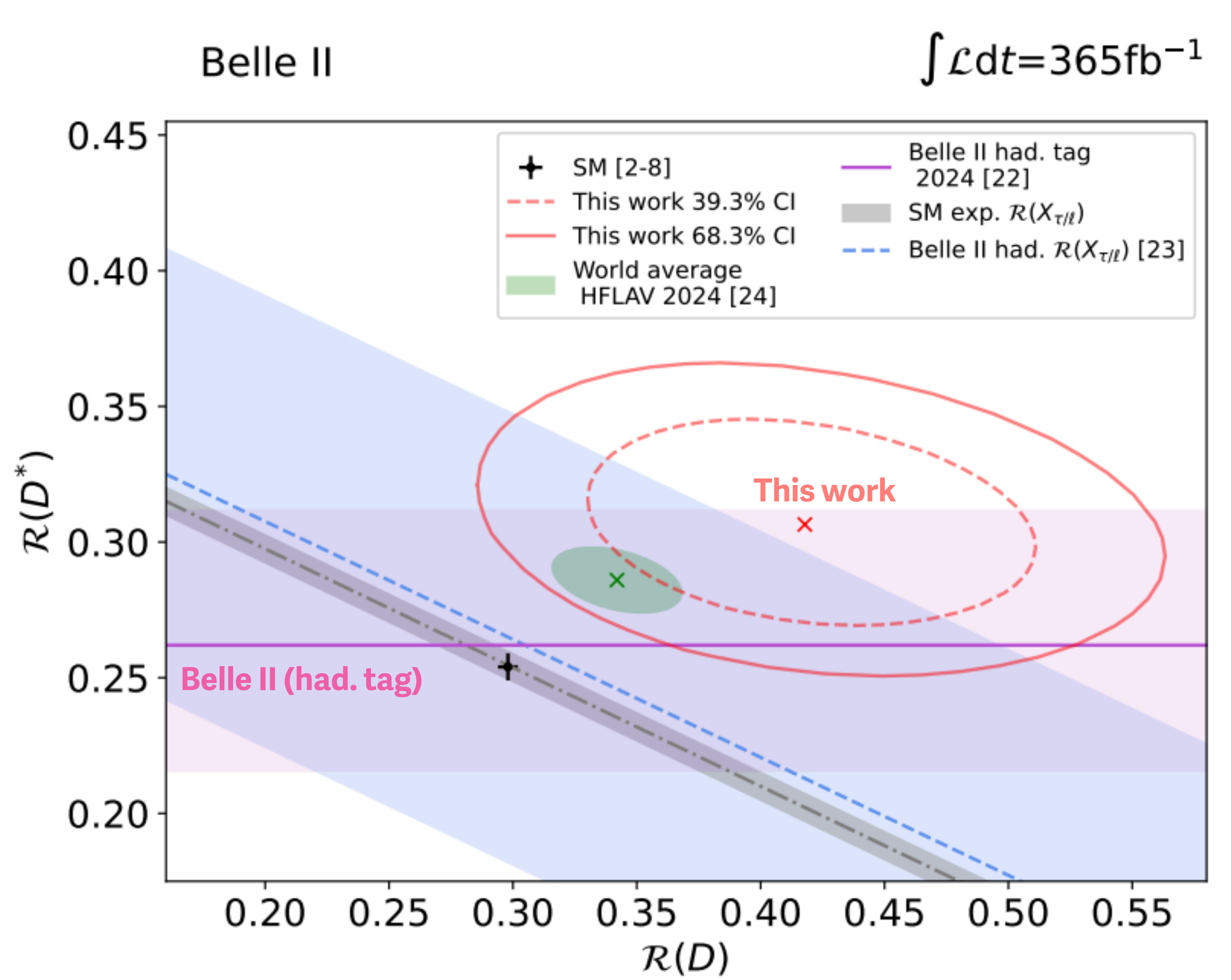
Results (Preliminary)

$$\mathcal{R}(D^+) = 0.418 \pm 0.074 \text{ (stat)} \pm 0.051 \text{ (syst)}$$
$$\mathcal{R}(D^{*+}) = 0.306 \pm 0.034 \text{ (stat)} \pm 0.018 \text{ (syst)}$$

with a correlation of $\rho = -0.24$

- Results are compatible with SM within 1.7σ
- Agrees with HFLAV24 average *
- Measurements dominated by statistical uncertainty
- Systematics dominated by limited statistics of simulations, MVA training, and template shapes [backup]

First SL-tagged results on $\mathcal{R}(D^{(*+)})$ from Belle II



HFLAV24

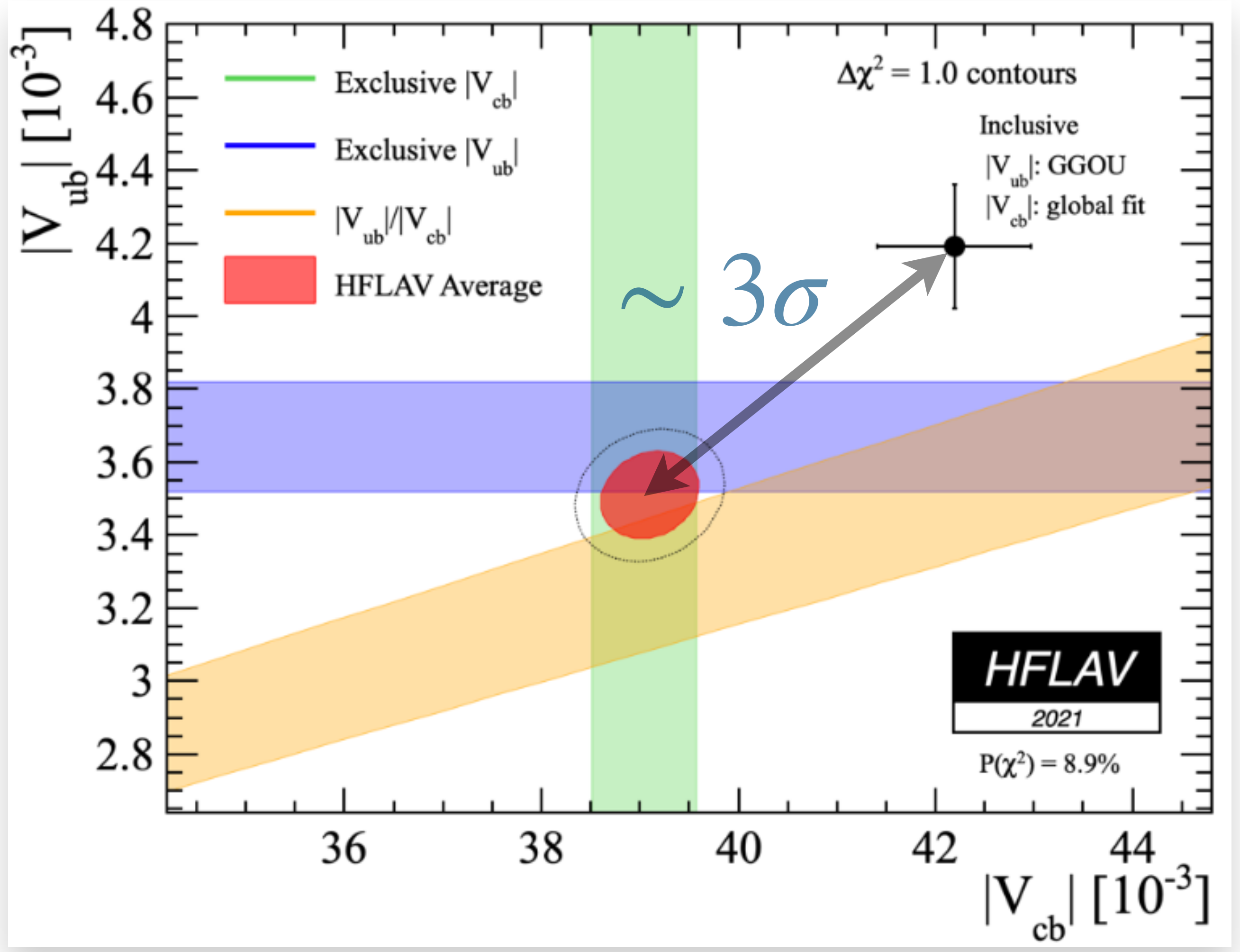
* $\mathcal{R}(D) = 0.342 \pm 0.026$
$\mathcal{R}(D^*) = 0.287 \pm 0.012$

Prologue: $|V_{cb}|$ measurement

Theory

$$|V_{cb}| = (42.2 \pm 0.5) \times 10^{-3} \quad \text{(inclusive)}$$
$$|V_{cb}| = (39.8 \pm 0.6) \times 10^{-3} \quad \text{(exclusive)}$$

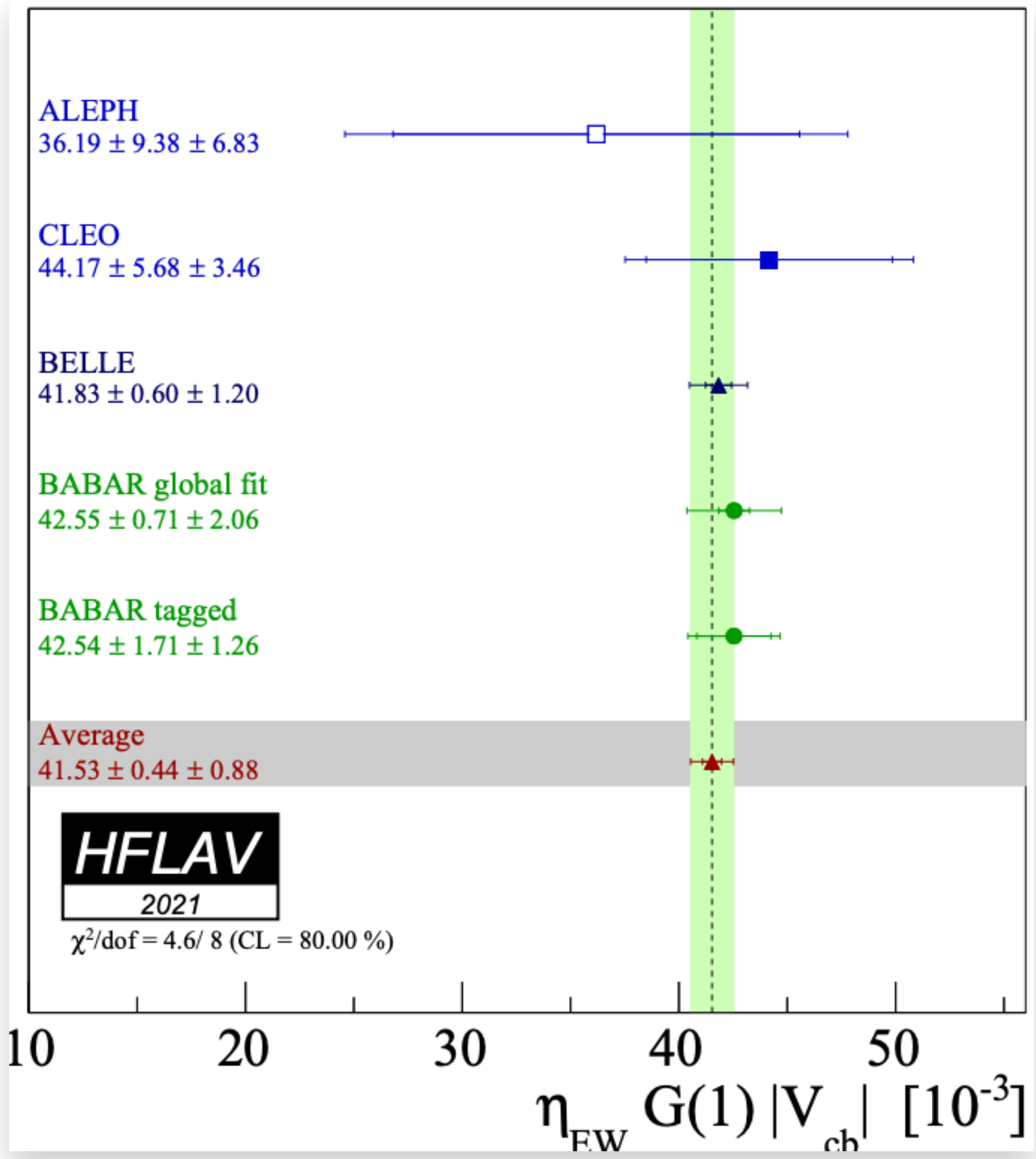
- Method: Exclusive ($B \to D^{(*)}\ell\nu$) and Inclusive ($B \to X_c\ell\nu$)
- Limitations:
  - Exclusive: Knowledge of the FFs (CLN, BCL) | Systematics dominate (expt.)
  - Inclusive: Higher order terms in HQE | Theoretical uncertainties dominate



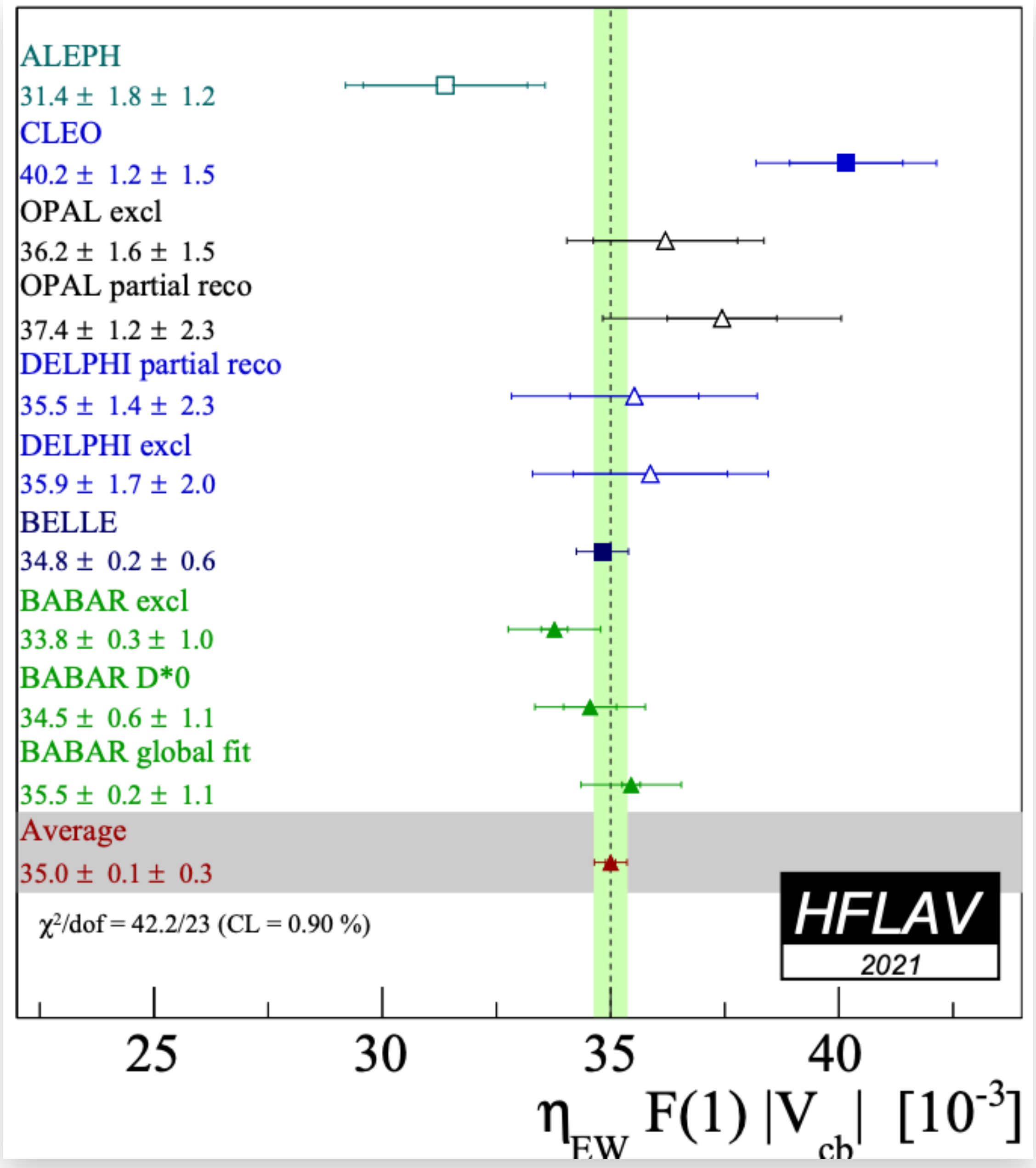
Experiment

- Consistently observe $\sim 3\sigma$ difference between exclusive and inclusive $|V_{cb}|, |V_{ub}|$ measurements
- Exclusive $|V_{cb}|$ from $B \to D\ell\nu$ can be advantageous: less theory unc. then $B \to D^*$ and do not suffer from slow-pion systematics

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



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

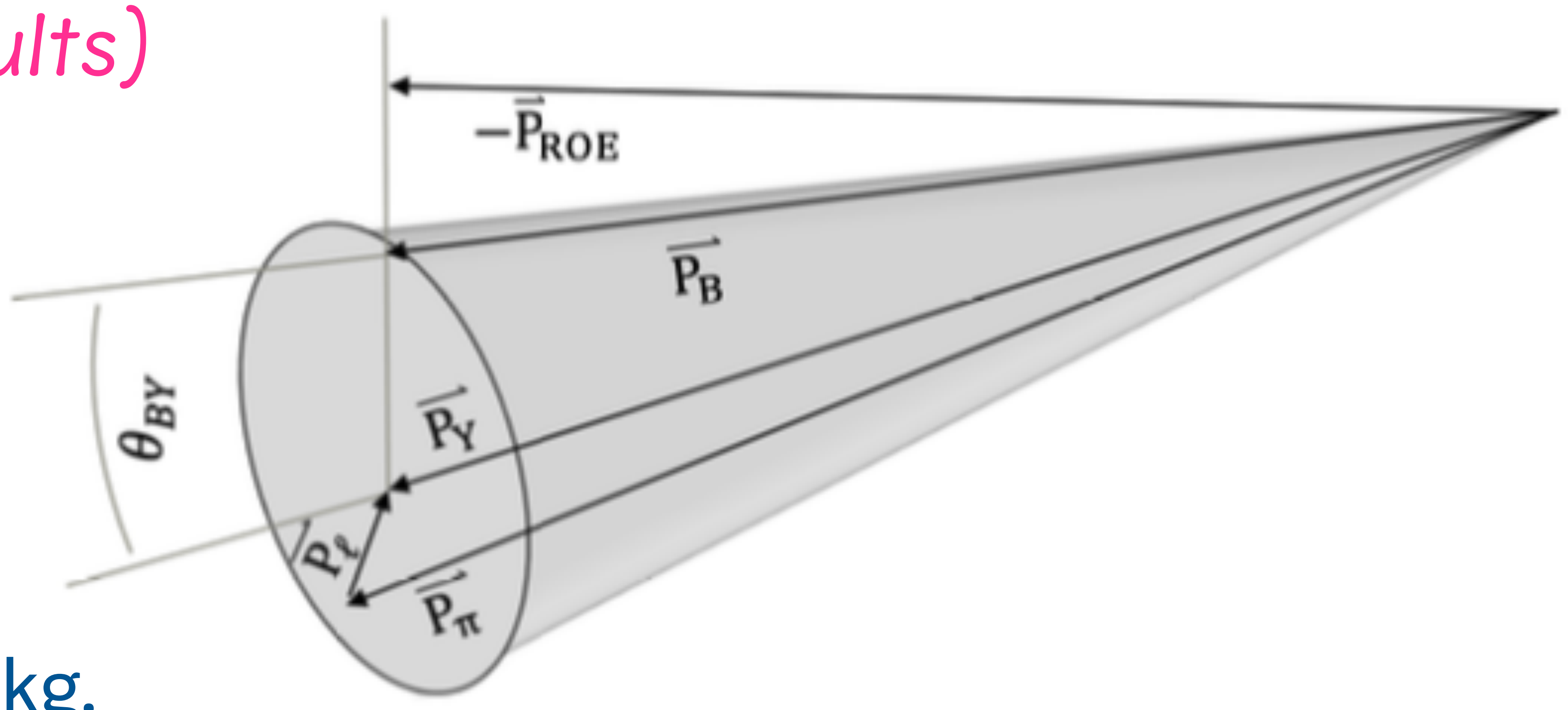


$|V_{cb}|$ from $B \to D\ell\nu$

New

To be submitted to Phys. Rev. D

Goal: $|V_{cb}|$ from $B \to D\ell\nu$ using untagged approach *(First results)*



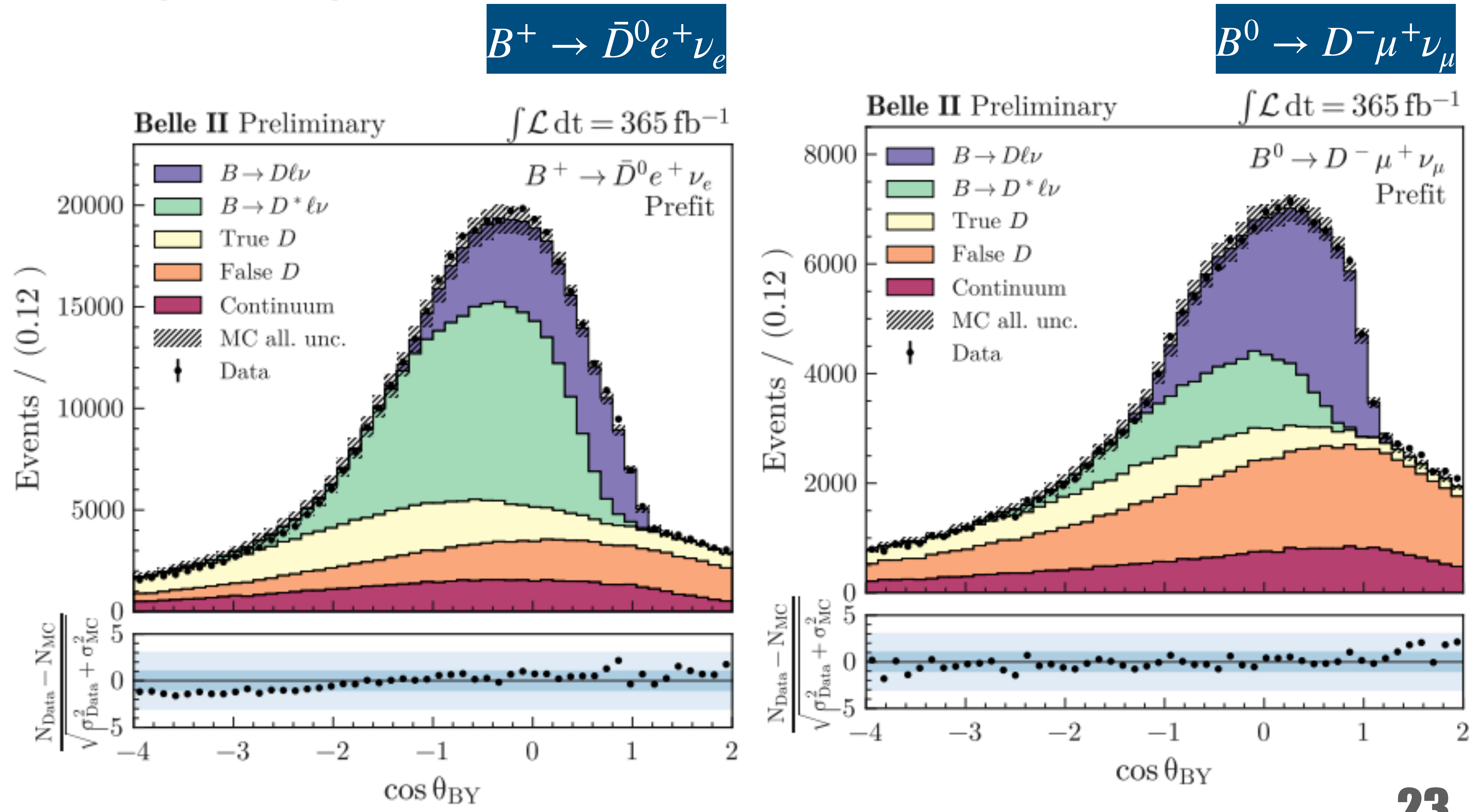
STEP I: Reconstruction

- Candidate $B \to D\ell\nu$'s are formed from ℓ (e, μ) and a D $(D \to K\pi, K\pi\pi)$
- $p^*_{\ell,D}$ selections are applied to select primary leptons and reject hadronic bkg.
- p_B^{miss} is estimated based on Diamond Frame (BaBar's) and ROE method (Belle's)

$$\cos\theta_{BY} = \frac{2E^*_B E^*_Y - M_B^2 - M_Y^2}{2|p^*_B||p^*_Y|}$$

- Finally, w ($\equiv v_B \cdot v_D$, 4-vel.) is accessed from p_B^{miss}
- "Feed-downs" from $B \to D^*\ell\nu$ are vetoed while continuum bkg. are suppressed using several kinematic selections

Good data / MC agreement



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

New

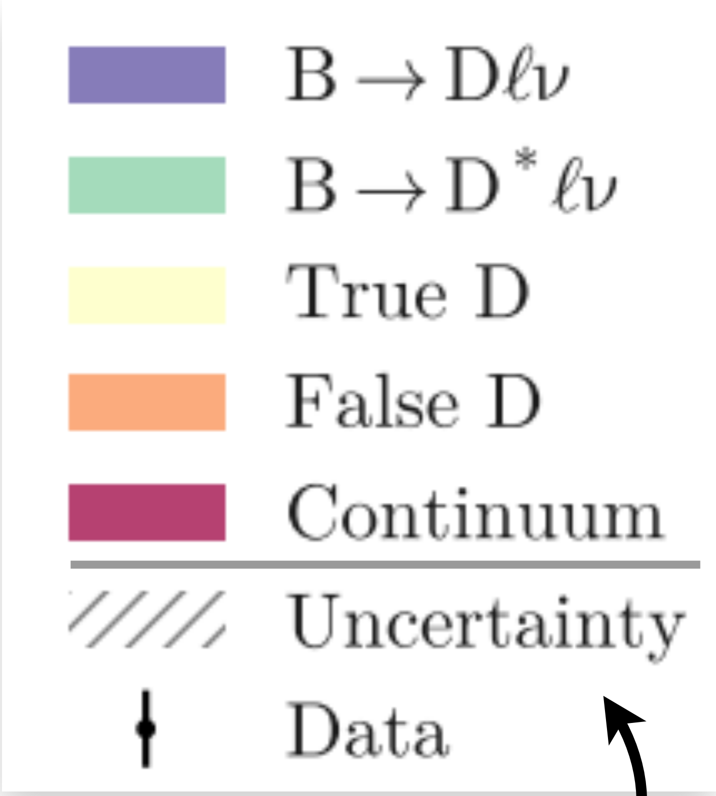
To be submitted to Phys. Rev. D

STEP II: Signal extraction

- Signal yield is extracted from a ML fit to a 10 **bin** dist. of $\cos\theta_{BY}$ and is performed simultaneously in 10 bins of w
- Results of BF are splitted into: $B^{+/0}$, e/μ modes

	HFLAV	
$B^+ \to \bar{D}^0\ell^+\nu_\ell$	2.21 ± 0.06	%
$B^0 \to D^-\ell^+\nu_\ell$	2.12 ± 0.06	%
$B \to D\ell\nu$	2.11 ± 0.05	%

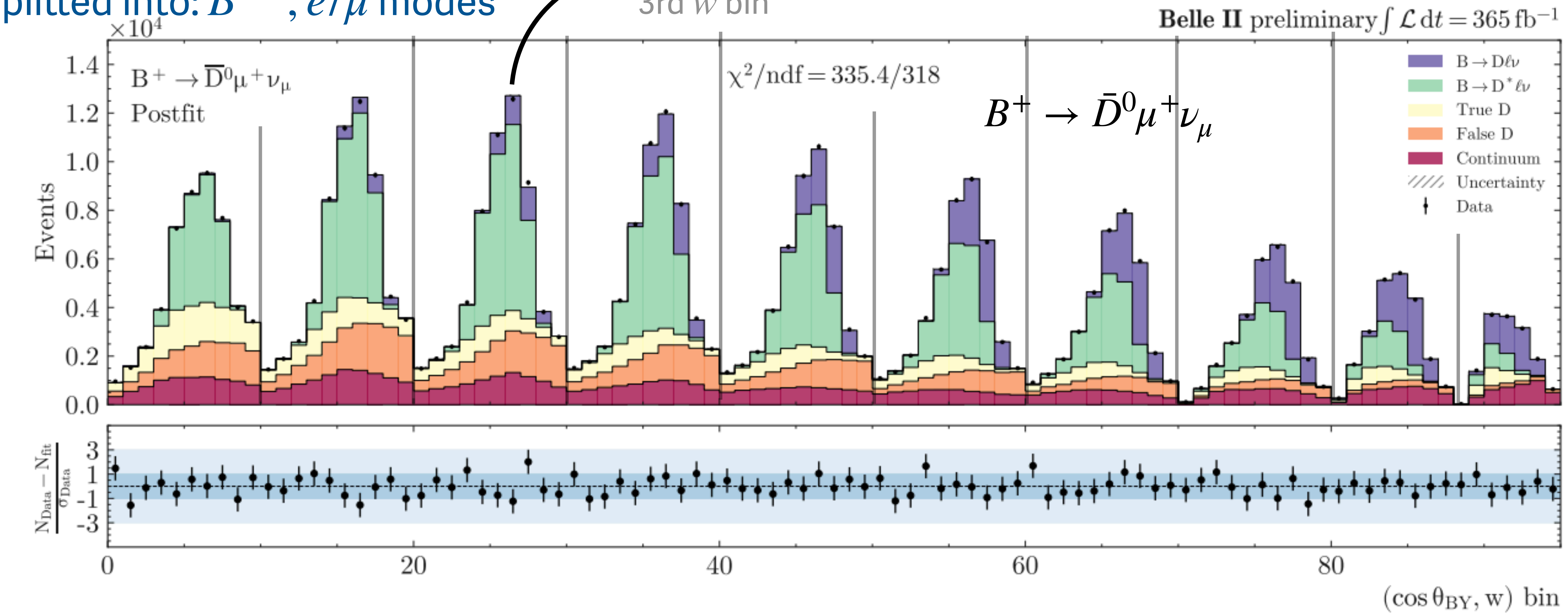
Fit templates



Total

7th $\cos\theta_{BY}$ bin,

3rd w bin



$B^+ \to \bar{D}^0\mu^+\nu_\mu$

[backup]

$\mathcal{B}(B^+ \to \bar{D}^0\ell^+\nu_\ell) = (2.31 \pm 0.10)\%$ *

$\mathcal{B}(B^0 \to D^-\ell^+\nu_\ell) = (2.06 \pm 0.12)\%$ *

*consistent with HFLAV24

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

New

To be submitted to Phys. Rev. D

STEP III: $|V_{cb}|$ extraction

$|V_{cb}| = (42.2 \pm 0.5) \times 10^{-3}$ (inclusive)
$|V_{cb}| = (39.8 \pm 0.6) \times 10^{-3}$ (exclusive)

$|V_{cb}|$ is extracted using χ^2 fits to the measured w spectra

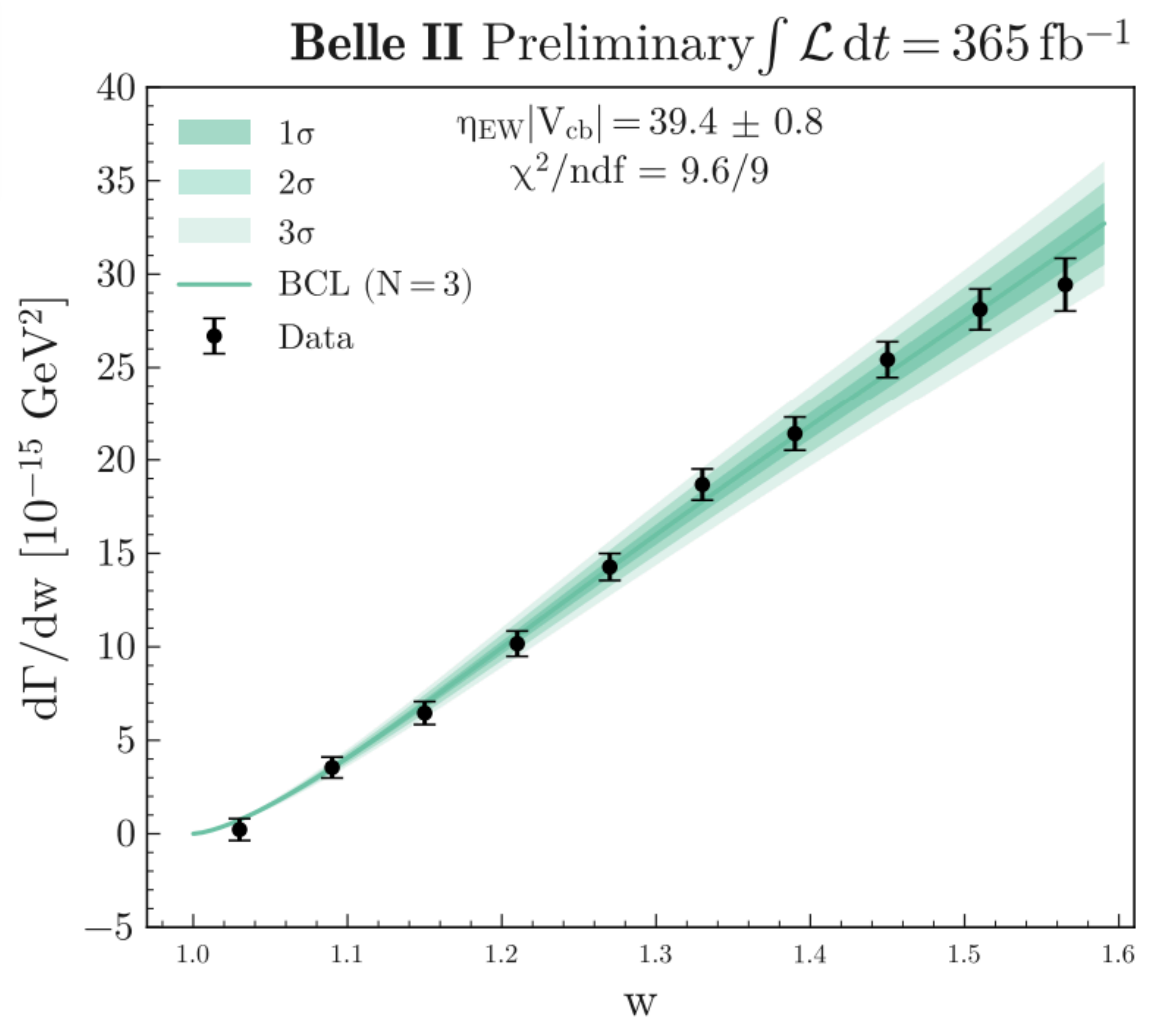
$$\chi^2 = \sum_{i,j}^{10} \left(\frac{\Delta\Gamma_i}{\Delta w} - \frac{\Delta\Gamma_{i,\mathrm{BCL}}}{\Delta w} \right) C_{ij}^{-1} \left(\frac{\Delta\Gamma_j}{\Delta w} - \frac{\Delta\Gamma_{j,\mathrm{BCL}}}{\Delta w} \right) + \chi^2_{\mathrm{theory}}$$

Theoretical prediction

BCL parametrisation of FF (5 free parameters)

Expt. obs.

Inverse covariance matrix



Parameters (5) of BCL parametrisation from fit

	Values	Correlation coefficients				
a_0^+	0.8959(92)	1	0.26	-0.38	0.95	0.51
a_1^+	-8.03(15)		1	0.17	0.33	0.86
a_2^+	49.3(31)			1	-0.31	0.16
a_0^0	0.7813(73)				1	0.47
a_1^0	-3.38(15)					1

Electroweak correction: 1.0066 ± 0.0002
[Nucl. Phys. B 196, 83 (1982)]

+ $\eta_{\mathrm{EW}}|V_{cb}| = 39.4 \pm 0.8$

Result (Preliminary)

$$|V_{cb}|_{\mathrm{BCL}} = (39.2 \pm 0.4_{\mathrm{stat.}} \pm 0.6_{\mathrm{sys.}} \pm 0.5_{\mathrm{th.}}) \times 10^{-3}$$

Most precise till date using $B \to D\ell\nu$

Among the dominant systematics include: limited simulation stats., estimation of N_{bb}, vertex fit corrections, background w modelling [backup]

Epilogue

All results are new since Moriond 2024

Hadronic decays of B mesons

arXiv:2412.19624 | Submitted to Phys. Rev. D

$$\mathcal{B}(B^0 \to \rho^+\rho^-) = (2.88^{+0.23+0.29}_{-0.22-0.27}) \times 10^{-5}$$
$$f_L = 0.921^{+0.024+0.017}_{-0.025-0.015},$$
$$S = -0.26 \pm 0.19 \pm 0.08,$$
$$C = -0.02 \pm 0.12^{+0.06}_{-0.05},$$

Belle II result improves ϕ_2 precision by ~8% ! Consistent with WA values!

Phys. Rev. D 110, L031102 (2024)

Quantity ($\times\mathcal{B}(\Omega_c^0 \to \Omega^-\pi^+)$)	Upper limit (at 95% CL)
$\mathcal{B}(B \to \bar{\Lambda}^0\Omega_c^0)$	9.7×10^{-8}
$\mathcal{B}(B \to \bar{\Lambda}^0\Omega_c(2770)^0)$	31.2×10^{-8}
$\mathcal{B}(B \to \bar{\Lambda}^0\bar{\Omega}_c^0)$	9.5×10^{-8}
$\mathcal{B}(B \to \bar{\Lambda}^0\bar{\Omega}_c(2770)^0)$	10.0×10^{-8}

First upper limit set for BNV decays from Belle

Missing energies leptonic decays of B mesons

arXiv: 2502.04885 | Submitted to Phys. Rev. D

$$\mathcal{B}(B^+ \to \tau^+\nu_\tau) = [1.24 \pm 0.41(\text{stat.}) \pm 0.19(\text{syst.})] \times 10^{-4}$$

$$|V_{ub}|_{B^+\to\tau^+\nu_\tau} = [4.41^{+0.74}_{-0.89}] \times 10^{-3}$$

Consistent with WA values! First leptonic results from Belle II with hadronic tagging approach

Missing energies semi-leptonic decays of B mesons

To be submitted to Phys. Rev. D

$$\mathcal{R}(D^+) = 0.418 \pm 0.074\ (\text{stat}) \pm 0.051\ (\text{syst})$$
$$\mathcal{R}(D^{*+}) = 0.306 \pm 0.034\ (\text{stat}) \pm 0.018\ (\text{syst})$$

Compatible with SM within 1.7σ !

First results from Belle II with semi-leptonic tagging approach

To be submitted to Phys. Rev. D

$$|V_{cb}|_{\text{BCL}} = (39.2 \pm 0.4_{\text{stat.}} \pm 0.6_{\text{sys.}} \pm 0.5_{\text{th.}}) \times 10^{-3}$$

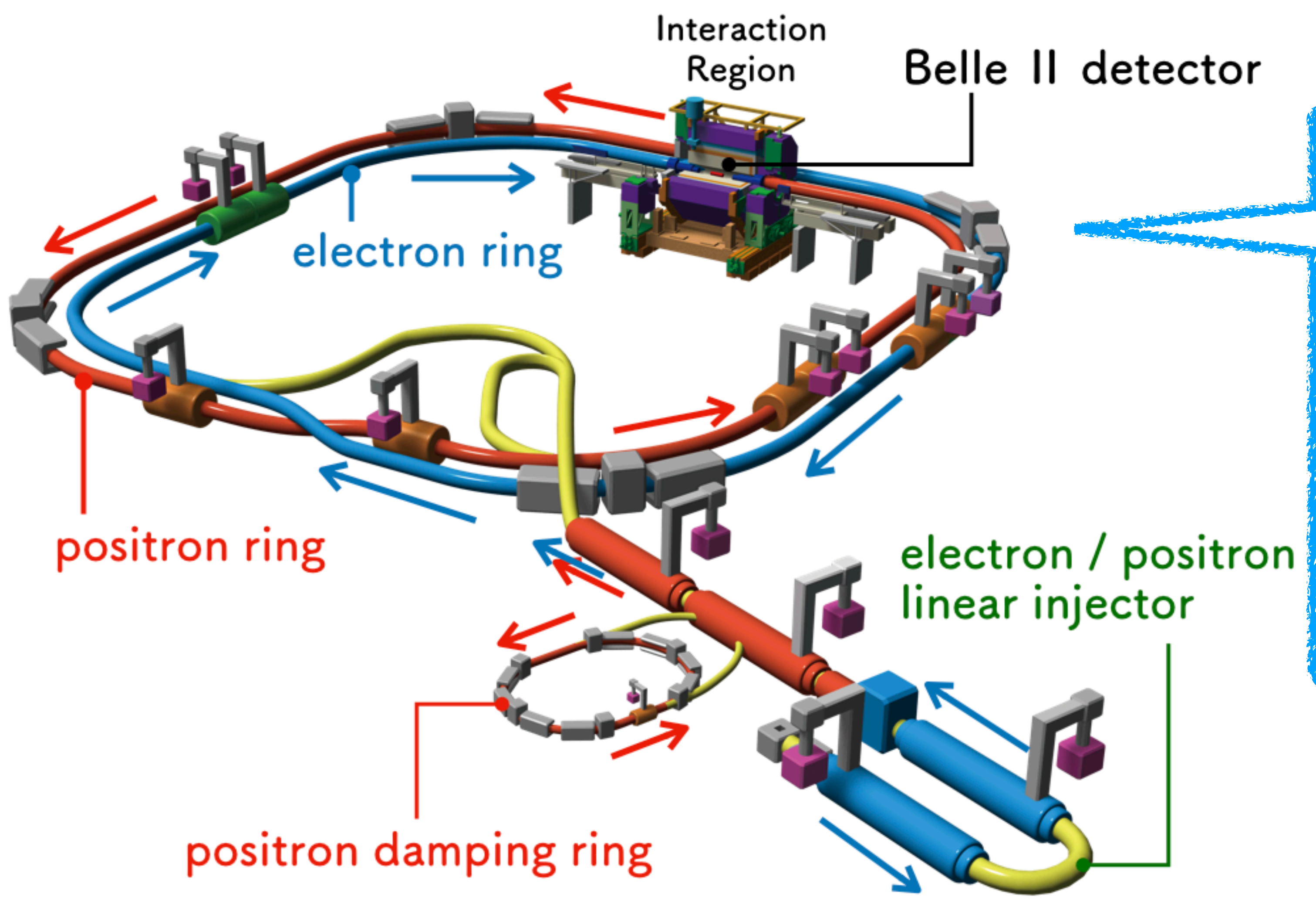
Most precise $|V_{cb}|$ value from $B \to D\ell\nu$

First results from Belle II with untagged approach

Thank You

Additional slides

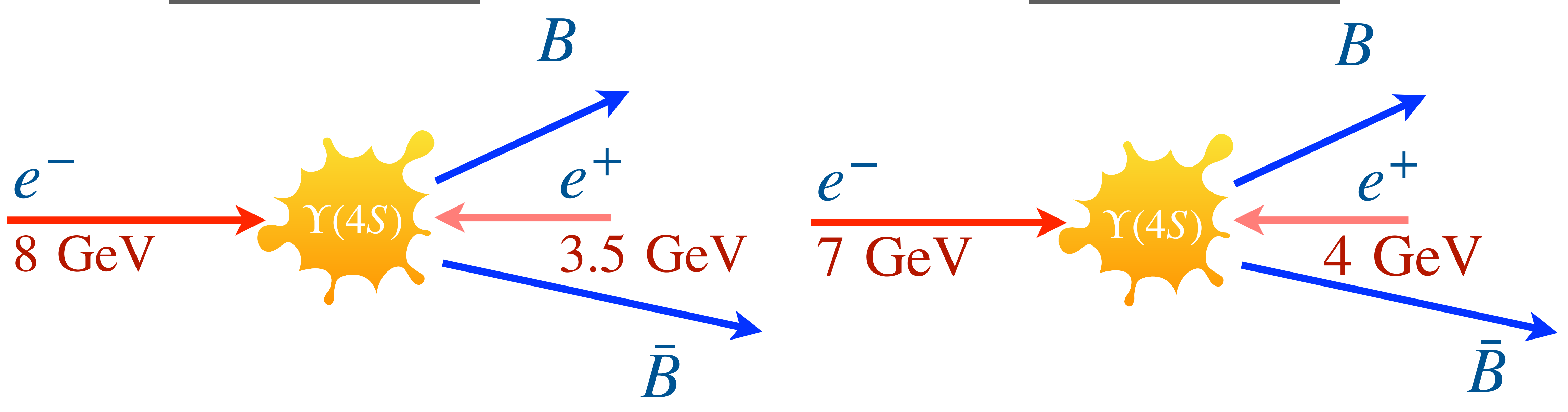
The SuperKEKB and the Belle II detector

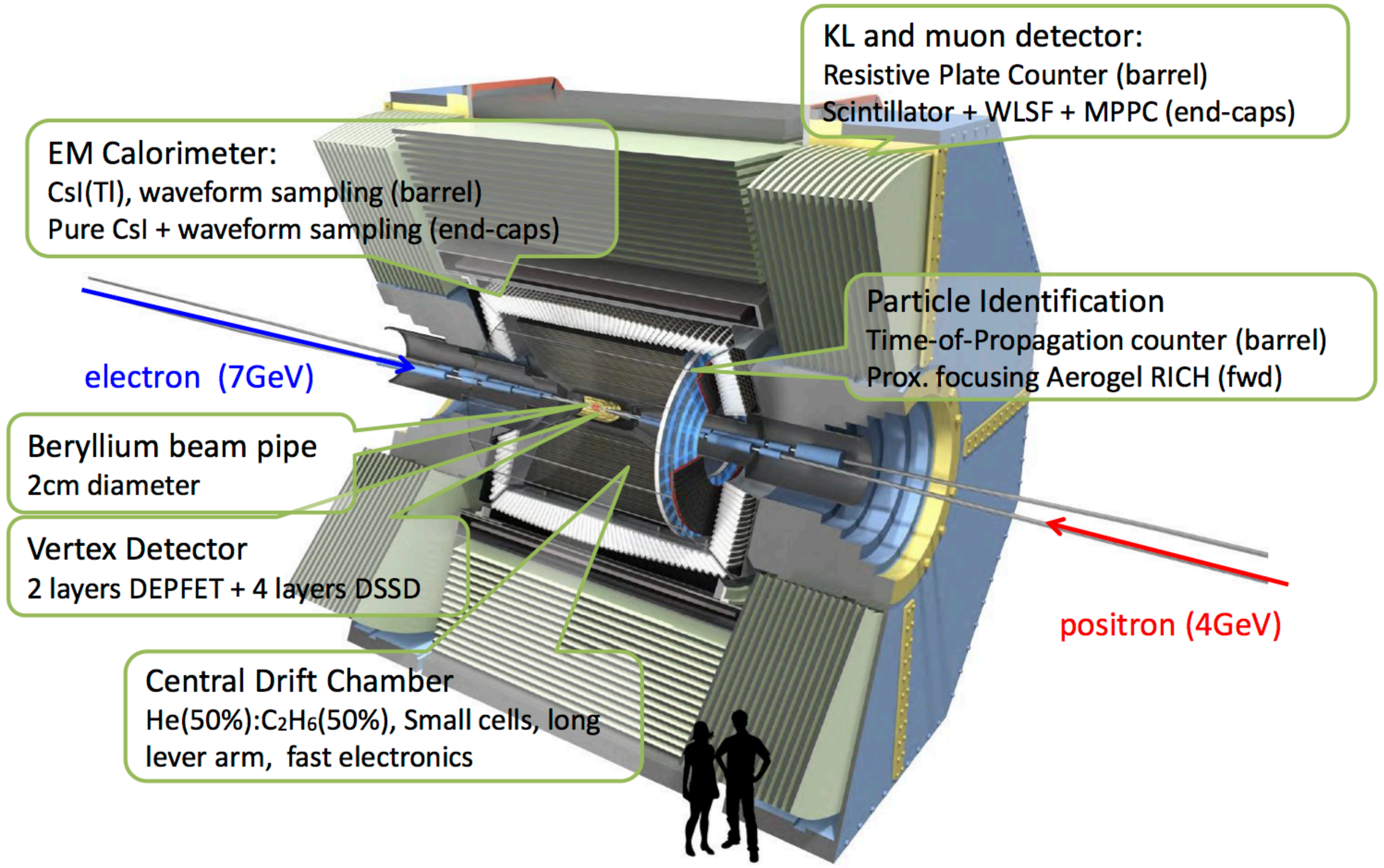


In comparison to KEKB

1/20 reduction in beam size (more effective collisions)

Lesser asymmetry in beam energies (to reduce bkg.)

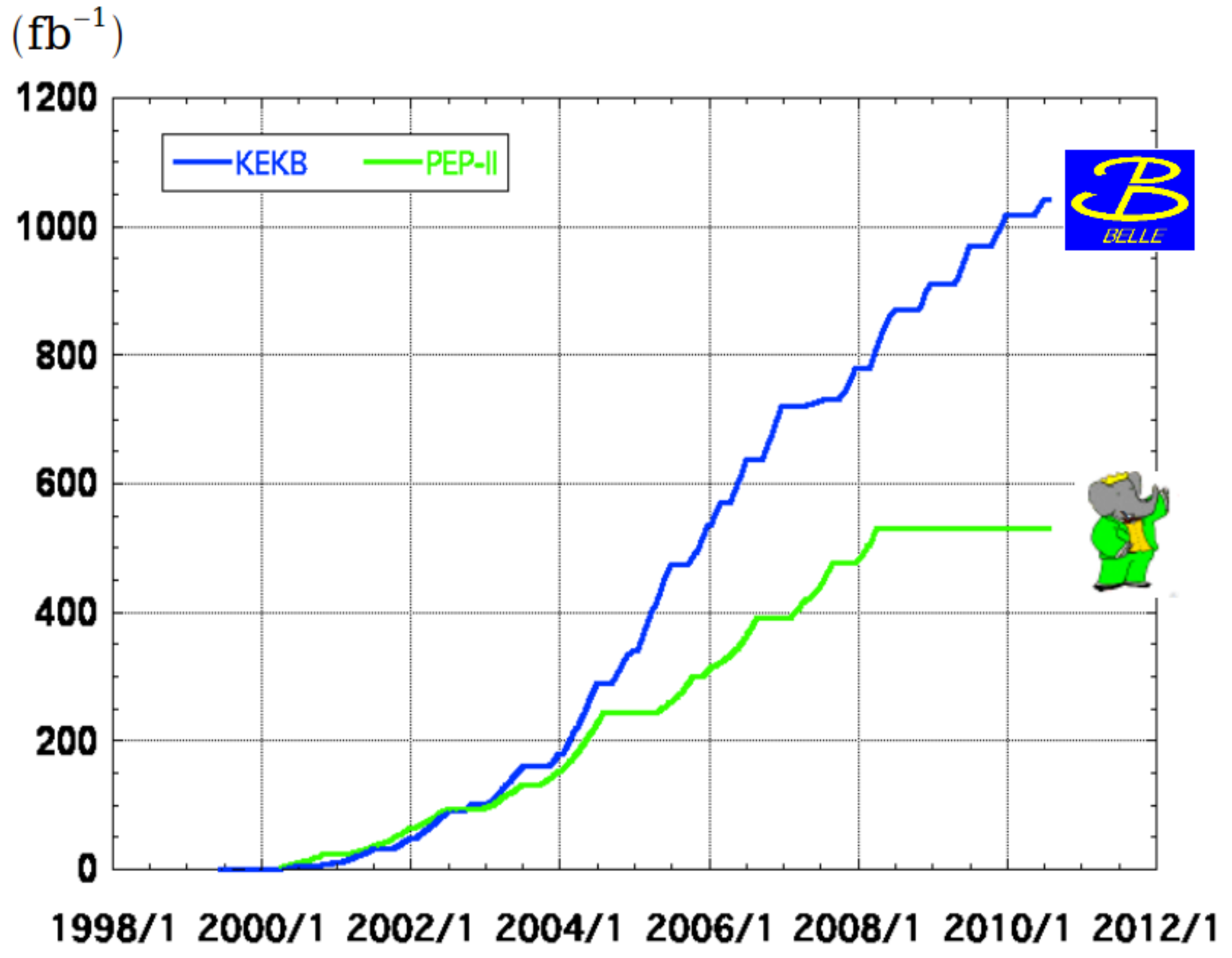




Belle II Performances

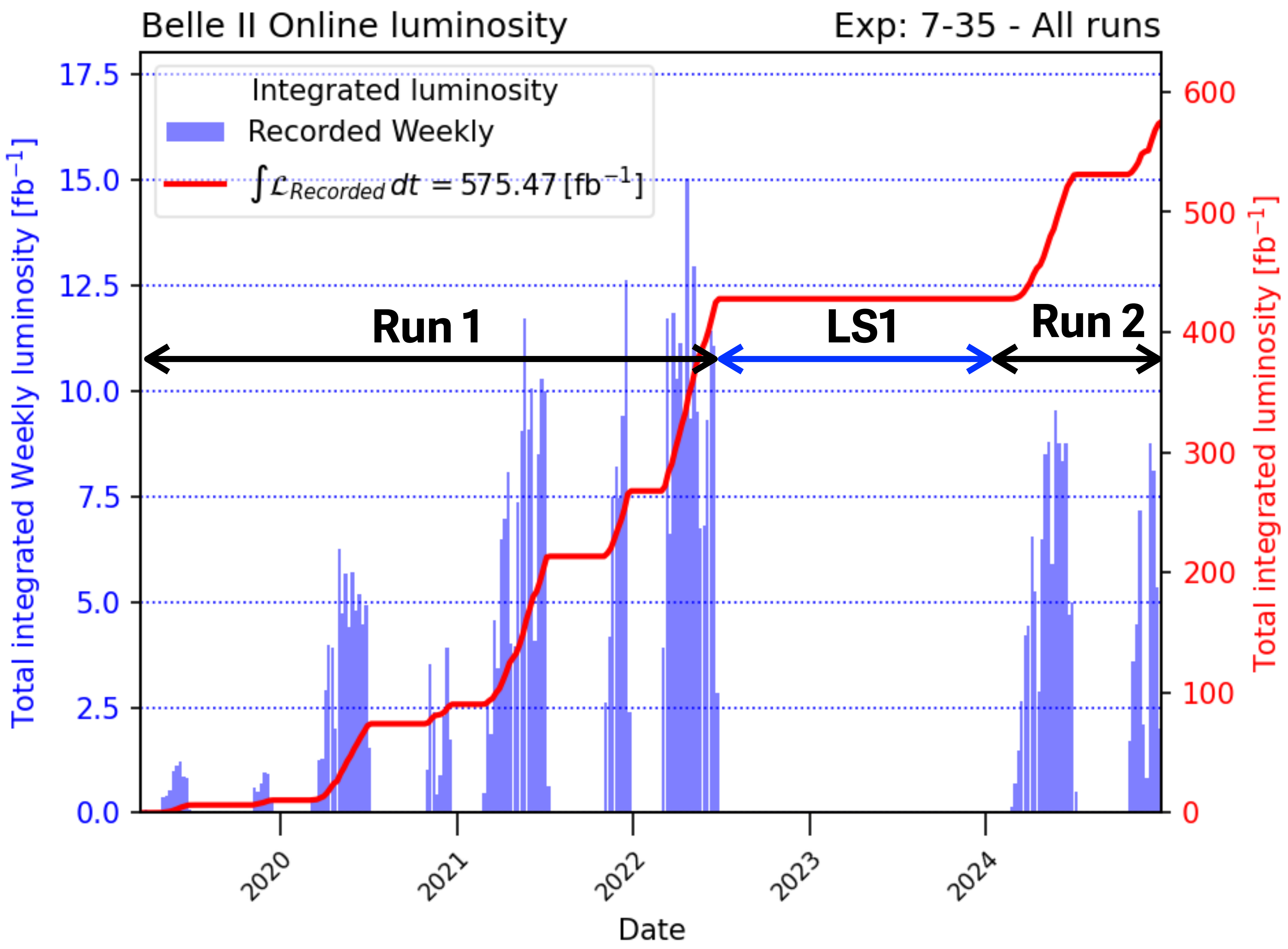
- VXD, $\sigma \sim 15\ \mu\mathrm{m}$
- CDC, $\sigma(p_\mathrm{T})/p_\mathrm{T} \sim 0.4\,\%$
- ECL, $\sigma(E)/E \sim 5\,\%$
- PID (SVD, ARICH, TOP, KLM)
  - K eff. $\sim 90\,\%$ (π mis – ID $\sim 5\%$)
  - μ ID eff. $\sim 90\,\%$ (π mis – ID $\sim 5\%$)

Luminosity records



> 1 ab^{-1}
On resonance:
$\Upsilon(5S)$: 121 fb^{-1}
$\Upsilon(4S)$: 711 fb^{-1}
$\Upsilon(3S)$: 3 fb^{-1}
$\Upsilon(2S)$: 25 fb^{-1}
$\Upsilon(1S)$: 6 fb^{-1}
Off reson./scan:
~ 100 fb^{-1}

~ 550 fb^{-1}
On resonance:
$\Upsilon(4S)$: 433 fb^{-1}
$\Upsilon(3S)$: 30 fb^{-1}
$\Upsilon(2S)$: 14 fb^{-1}
Off resonance:
~ 54 fb^{-1}



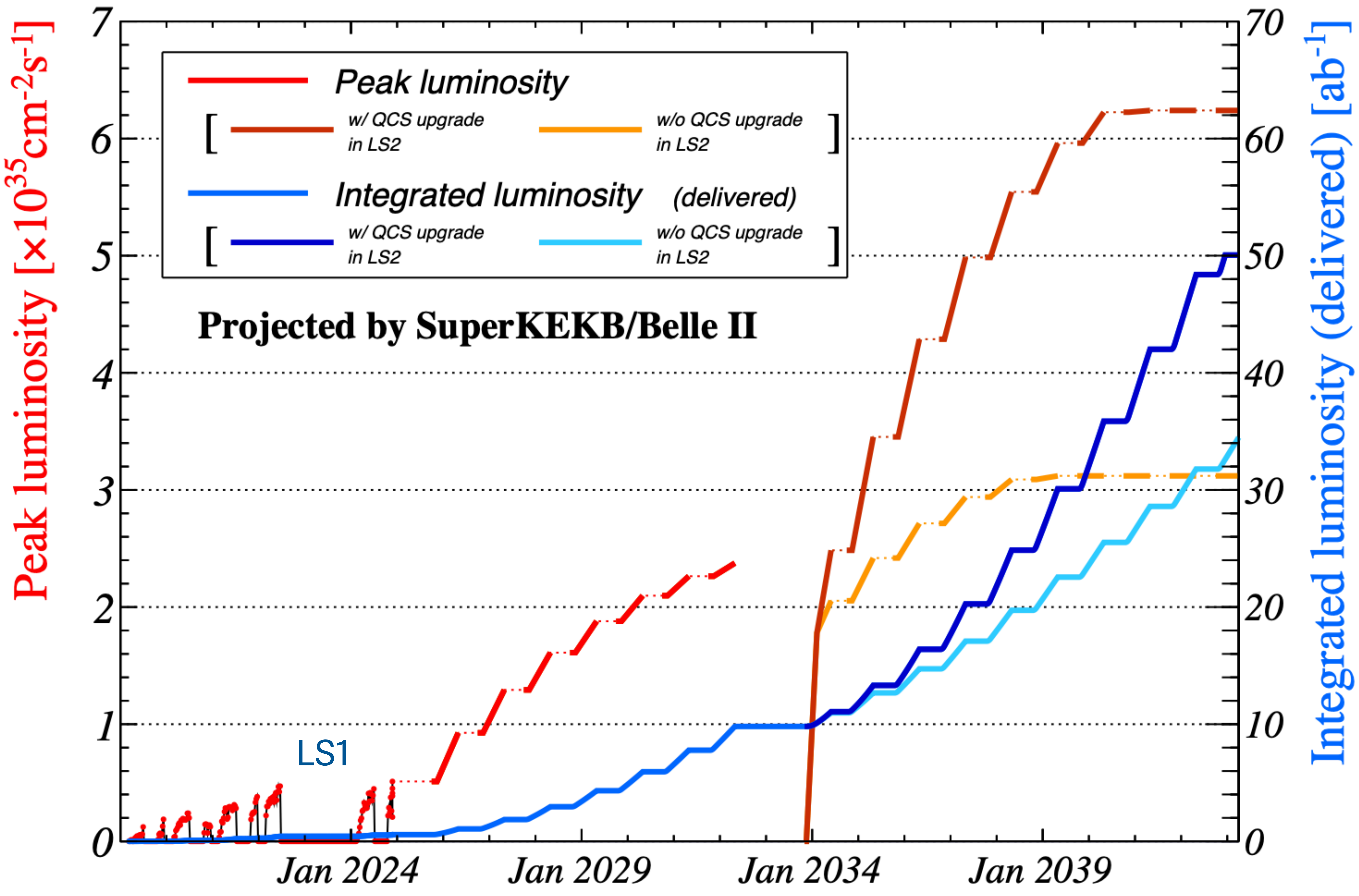
World Record Luminosity of 2.11 x 10^{34} cm^{-2} s^{-1} achieved (June 2009) with crab cavities at KEKB

New record of peak luminosity

5.105 x 10^{34} cm^{-2} s^{-1}

27-12-2024 at 13:40 hrs JST

Luminosity projection plot

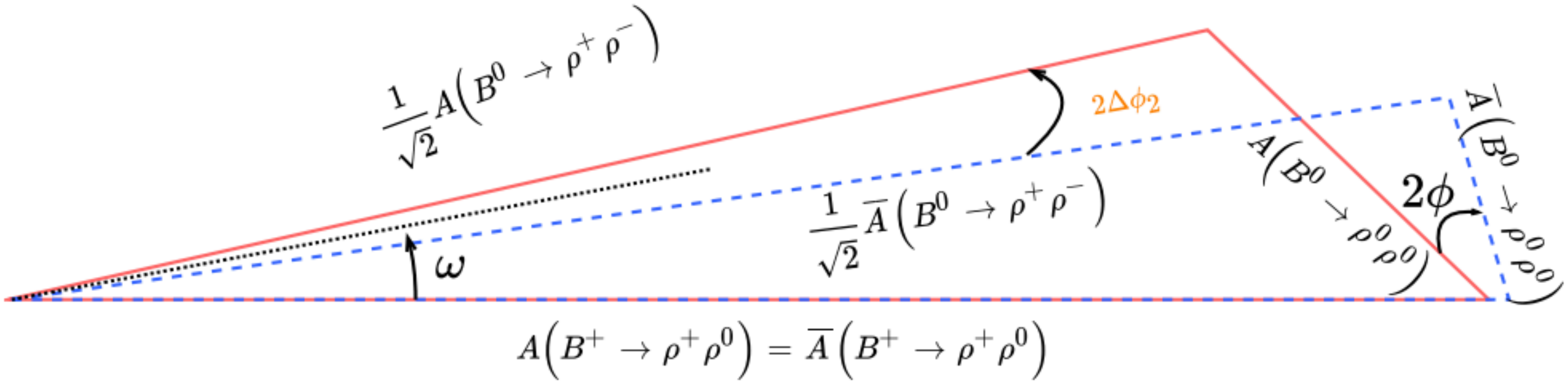


$B^0 \to \rho^+\rho^-$

New

arXiv:2412.19624 | Submitted to Phys. Rev. D

Isospin triangle for $B \to \rho\rho$



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

New

arXiv:2412.19624 | Submitted to Phys. Rev. D

Belle II

Table of systematics on $\mathcal{B}$ and f_L

Source	$\mathcal{B}$ [%]	$f_L[10^{-2}]$
Tracking	± 0.54	—
π^0 efficiency	± 7.67	—
PID	± 0.08	—
$\mathcal{T}_C$	± 2.87	—
MC sample size	± 0.24	± 0.2
Single candidate selection	± 0.55	± 0.3
SCF ratio	$^{+2.97}_{-2.45}$	$^{+0.2}_{-0.3}$
$\mathcal{B}$'s of peaking backgrounds	$^{+0.94}_{-0.98}$	± 0.1
$\tau^+\tau^-$ background yield	$^{+0.65}_{-0.69}$	± 0.0
Signal model	$^{+1.14}_{-2.02}$	± 0.2
$q\bar{q}$ model	$^{+0.49}_{-0.51}$	$^{+0.1}_{-0.2}$
$B\bar{B}$ model	$^{+1.00}_{-0.40}$	$^{+0.3}_{-0.1}$
$\tau^+\tau^-$ model	$^{+0.17}_{-0.26}$	$^{+0.0}_{-0.1}$
Peaking model	$^{+1.37}_{-1.01}$	$^{+0.3}_{-0.5}$
Interference	± 1.20	± 0.5
Data-MC mis-modeling	$^{+3.51}_{-1.70}$	$^{+0.8}_{-0.3}$
Fit bias	± 1.03	± 1.2
f_{+-}/f_{00}	± 1.51	—
N_{BB}	± 1.45	—
Total systematic uncertainty	$^{+10.07}_{-9.51}$	$^{+1.7}_{-1.5}$
Statistical uncertainty	$^{+7.93}_{-7.58}$	$^{+2.4}_{-2.5}$

Table of systematics on S and C

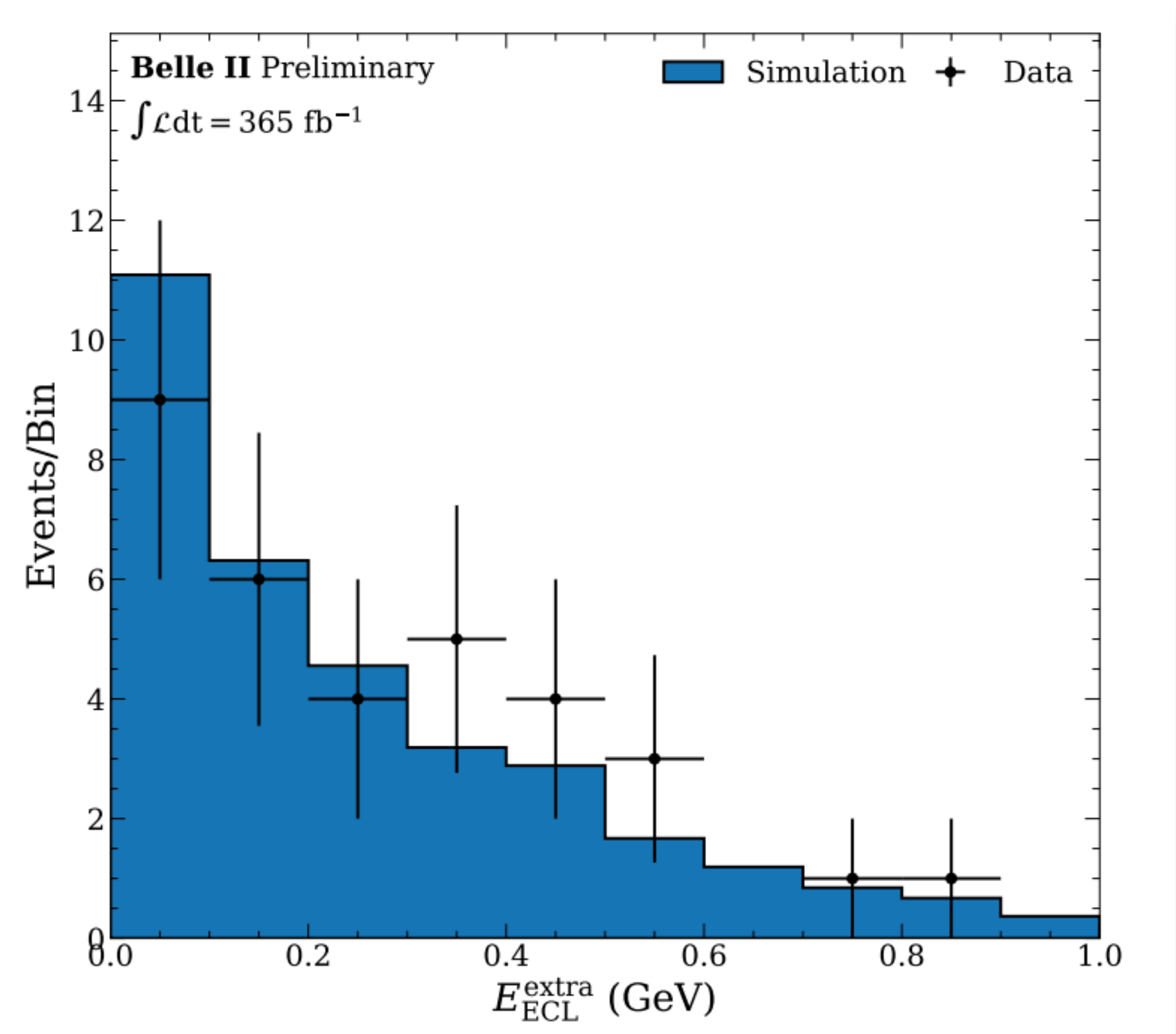
Source	$S[10^{-2}]$	$C[10^{-2}]$
$\mathcal{B}$'s of peaking backgrounds	$^{+0.6}_{-0.5}$	± 0.1
$\tau\tau$ background yield	± 0.9	$^{+0.0}_{-0.1}$
Data-MC mis-modeling	$^{+0.6}_{-1.1}$	$^{+1.5}_{-0.6}$
Single candidate selection	± 1.3	± 1.9
SCF ratio	$^{+0.5}_{-0.4}$	$^{+0.7}_{-0.0}$
Signal model	$^{+1.1}_{-1.4}$	$^{+0.3}_{-0.4}$
$q\bar{q}$ model	$^{+2.2}_{-1.0}$	± 0.2
$B\bar{B}$ model	± 0.9	$^{+0.7}_{-0.5}$
$\tau^+\tau^-$ model	± 0.1	± 0.0
Peaking model	$^{+0.8}_{-0.4}$	$^{+0.2}_{-0.4}$
Fit bias	± 2.0	± 0.6
Interference	± 2.8	± 1.7
Resolution	$^{+3.4}_{-4.4}$	$^{+1.9}_{-1.4}$
Δt PDF for $q\bar{q}$ and $B\bar{B}$	$^{+3.8}_{-1.8}$	$^{+0.7}_{-0.1}$
Tag side interference	± 0.5	± 2.1
Wrong tag fraction	$^{+0.2}_{-0.3}$	± 0.5
Background CP violation	$^{+3.8}_{-3.6}$	$^{+4.2}_{-3.7}$
CP violation in TP signal	$^{+0.8}_{-0.2}$	$^{+0.2}_{-0.4}$
Tracking detector misalignment	± 1.4	± 0.5
τ_{B^0} and Δm_d	$^{+1.4}_{-1.6}$	± 0.3
Total systematic uncertainty	$^{+8.2}_{-7.8}$	$^{+6.1}_{-5.3}$
Statistical uncertainty	± 18.8	± 12.1

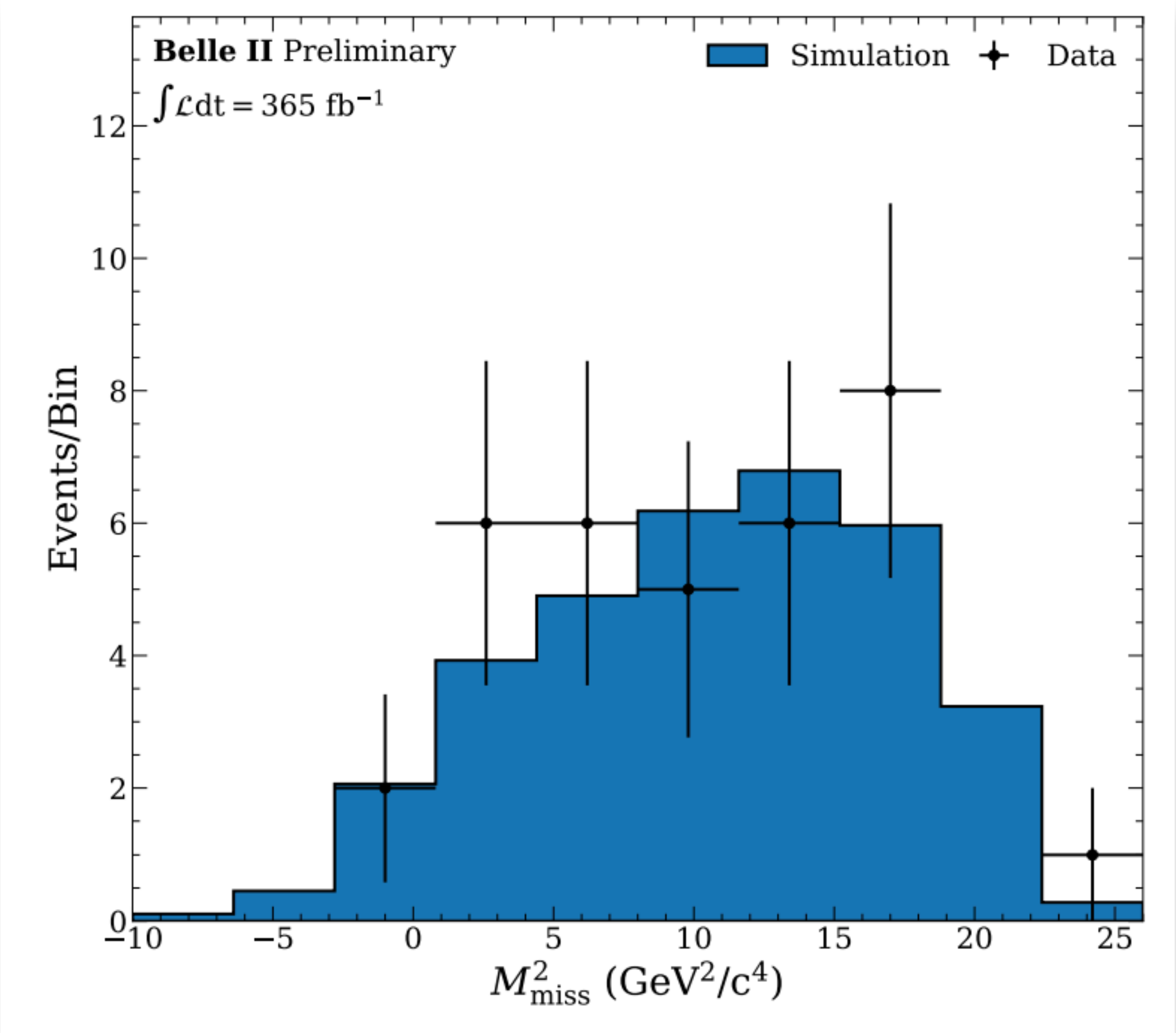
$B^+ \to \tau^+\nu$

New arXiv: 2502.04885 | Submitted to Phys. Rev. D

- Validation:
  - Signal embedding procedure using $B^+ \to K^+ J/\psi$ sample

Signal embedded control channels





TAB. V. Observed values of the signal yields and branching fractions, obtained from single fits for each τ^+ decay mode and the simultaneous fit.

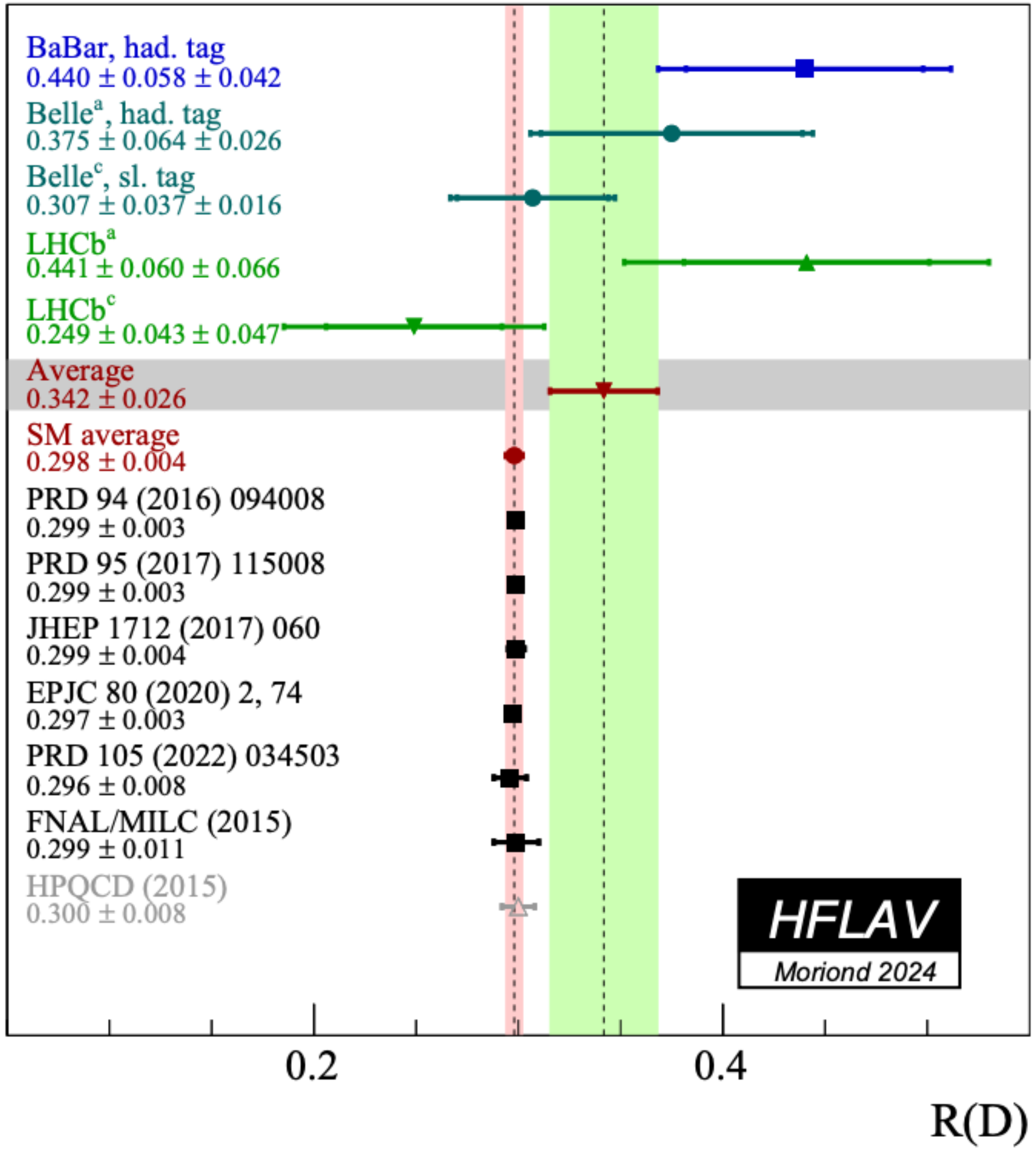
Decay mode	n_s	$\mathcal{B}(10^{-4})$
Simultaneous	94 ± 31	1.24 ± 0.41
$e^+ \nu_e \overline{\nu}_\tau$	13 ± 16	0.51 ± 0.63
$\mu^+ \nu_\mu \overline{\nu}_\tau$	40 ± 20	1.67 ± 0.83
$\pi^+ \overline{\nu}_\tau$	31 ± 13	2.28 ± 0.93
$\rho^+ \overline{\nu}_\tau$	6 ± 25	0.42 ± 1.82

Reco \ True	e^+ (%)	μ^+ (%)	π^+ (%)	ρ^+ (%)	other(%)
e^+	97	0.1	0.1	0	2.8
μ^+	0	87	0.9	0.1	12
π^+	0.1	3.3	55.7	16	24.9
ρ^+	0.4	4.5	27.8	61.2	6.1

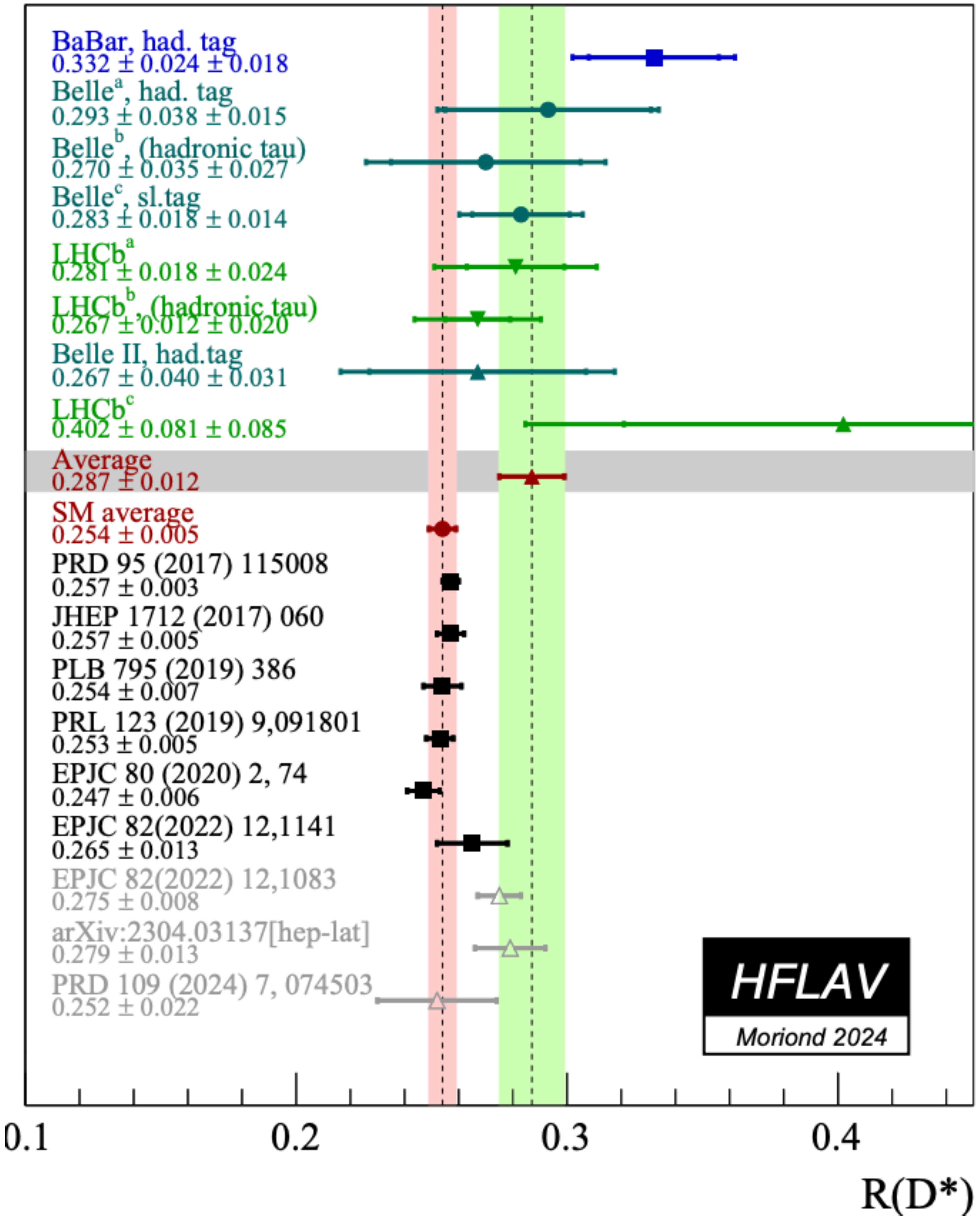
Table of systematics

Source	Syst.
Simulation statistics	13.3%
Fit variables PDF corrections	5.5%
Decays branching fractions in MC	4.1%
Tag B^- reconstruction efficiency	2.2%
Continuum reweighting	1.9%
π^0 reconstruction efficiency	0.9%
Continuum normalization	0.7%
Particle identification	0.6%
Number of produced $\Upsilon(4S)$	1.5%
Fraction of B^+B^- pairs	2.1%
Tracking efficiency	0.2%
Total	15.5%

$R(D^+)$ and $R(D^{*+})$



BaBar, had. tag
0.440 ± 0.058 ± 0.042
Belle[a], had. tag
0.375 ± 0.064 ± 0.026
Belle[c], sl. tag
0.307 ± 0.037 ± 0.016
LHCb[a]
0.441 ± 0.060 ± 0.066
LHCb[c]
0.249 ± 0.043 ± 0.047
Average
0.342 ± 0.026
SM average
0.298 ± 0.004
PRD 94 (2016) 094008
0.299 ± 0.003
PRD 95 (2017) 115008
0.299 ± 0.003
JHEP 1712 (2017) 060
0.299 ± 0.004
EPJC 80 (2020) 2, 74
0.297 ± 0.003
PRD 105 (2022) 034503
0.296 ± 0.008
FNAL/MILC (2015)
0.299 ± 0.011
HPQCD (2015)
0.300 ± 0.008
HFLAV
Moriond 2024
0.2
0.4
R(D)



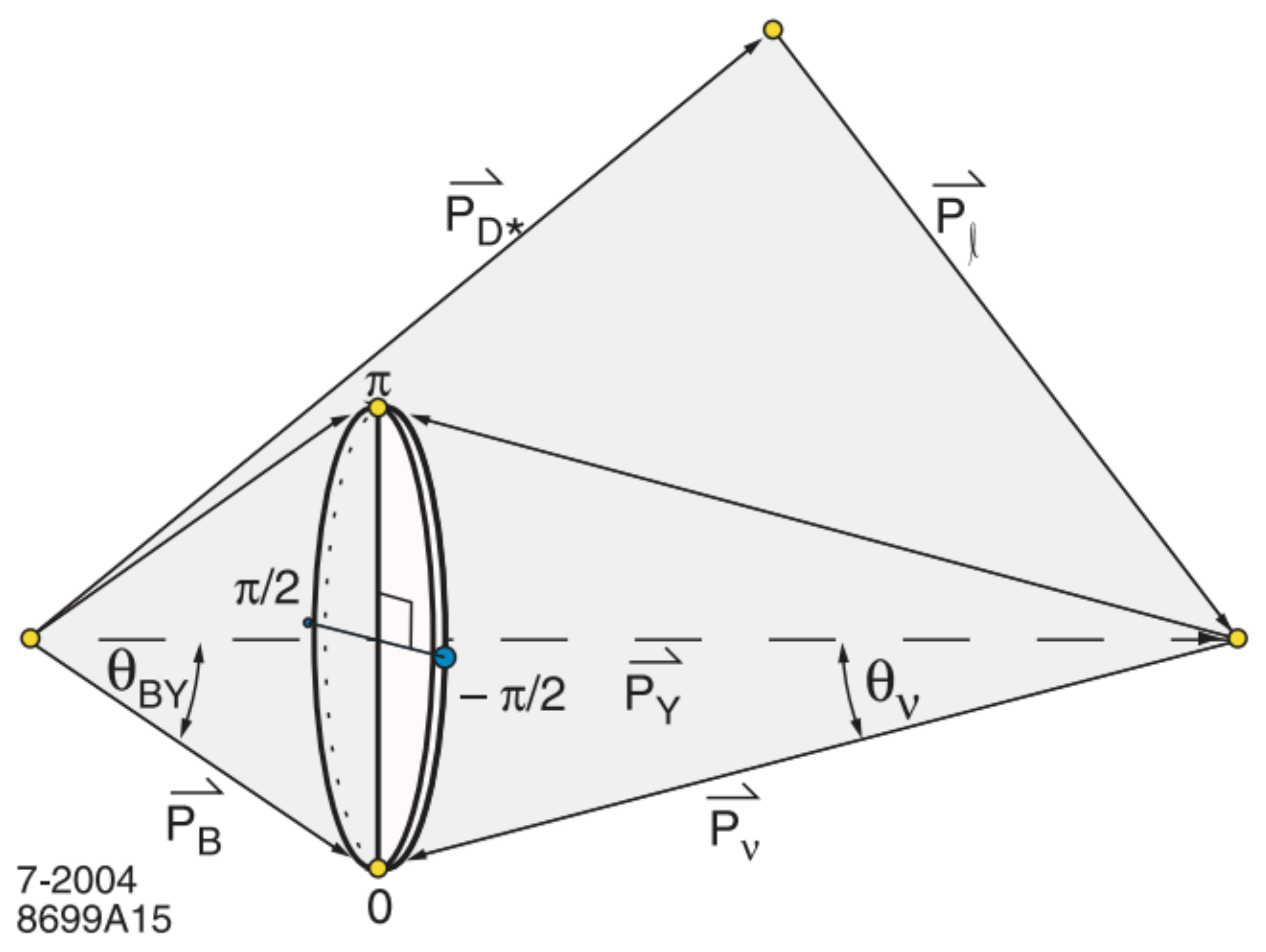
BaBar, had. tag
0.332 ± 0.024 ± 0.018
Belle[a], had. tag
0.293 ± 0.038 ± 0.015
Belle[b], (hadronic tau)
0.270 ± 0.035 ± 0.027
Belle[c], sl.tag
0.283 ± 0.018 ± 0.014
LHCb[a]
0.281 ± 0.018 ± 0.024
LHCb[b], (hadronic tau)
0.267 ± 0.012 ± 0.020
Belle II, had.tag
0.267 ± 0.040 ± 0.031
LHCb[c]
0.402 ± 0.081 ± 0.085
Average
0.287 ± 0.012
SM average
0.254 ± 0.005
PRD 95 (2017) 115008
0.257 ± 0.003
JHEP 1712 (2017) 060
0.257 ± 0.005
PLB 795 (2019) 386
0.254 ± 0.007
PRL 123 (2019) 9,091801
0.253 ± 0.005
EPJC 80 (2020) 2, 74
0.247 ± 0.006
EPJC 82(2022) 12,1141
0.265 ± 0.013
EPJC 82(2022) 12,1083
0.275 ± 0.008
arXiv:2304.03137[hep-lat]
0.279 ± 0.013
PRD 109 (2024) 7, 074503
0.252 ± 0.022
HFLAV
Moriond 2024
0.1
0.2
0.3
0.4
R(D*)

$R(D^+)$ and $R(D^{*+})$

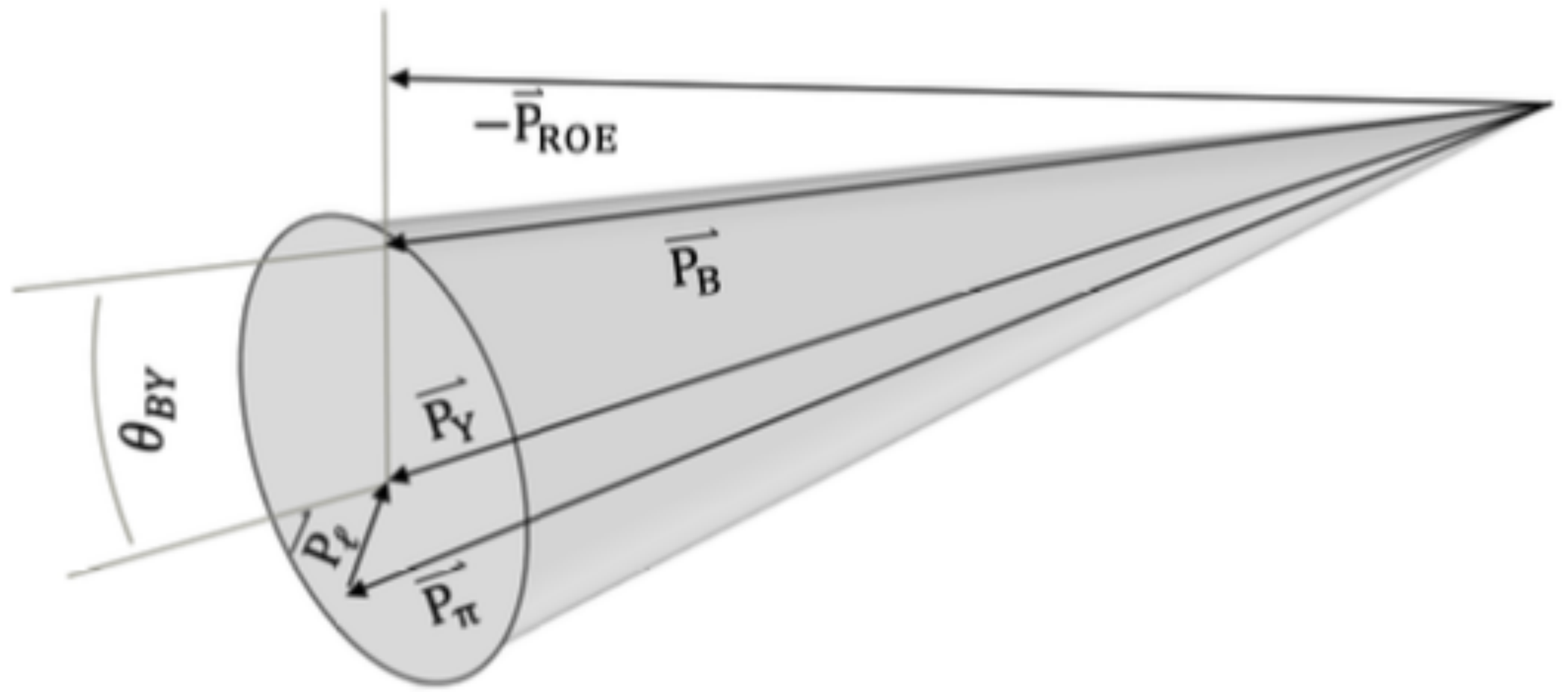
New To be submitted to Phys. Rev. D

Belle II

Diamond Frame (BaBar), [PRD 74 (Nov, 2006) 092004]



ROE method (Belle)



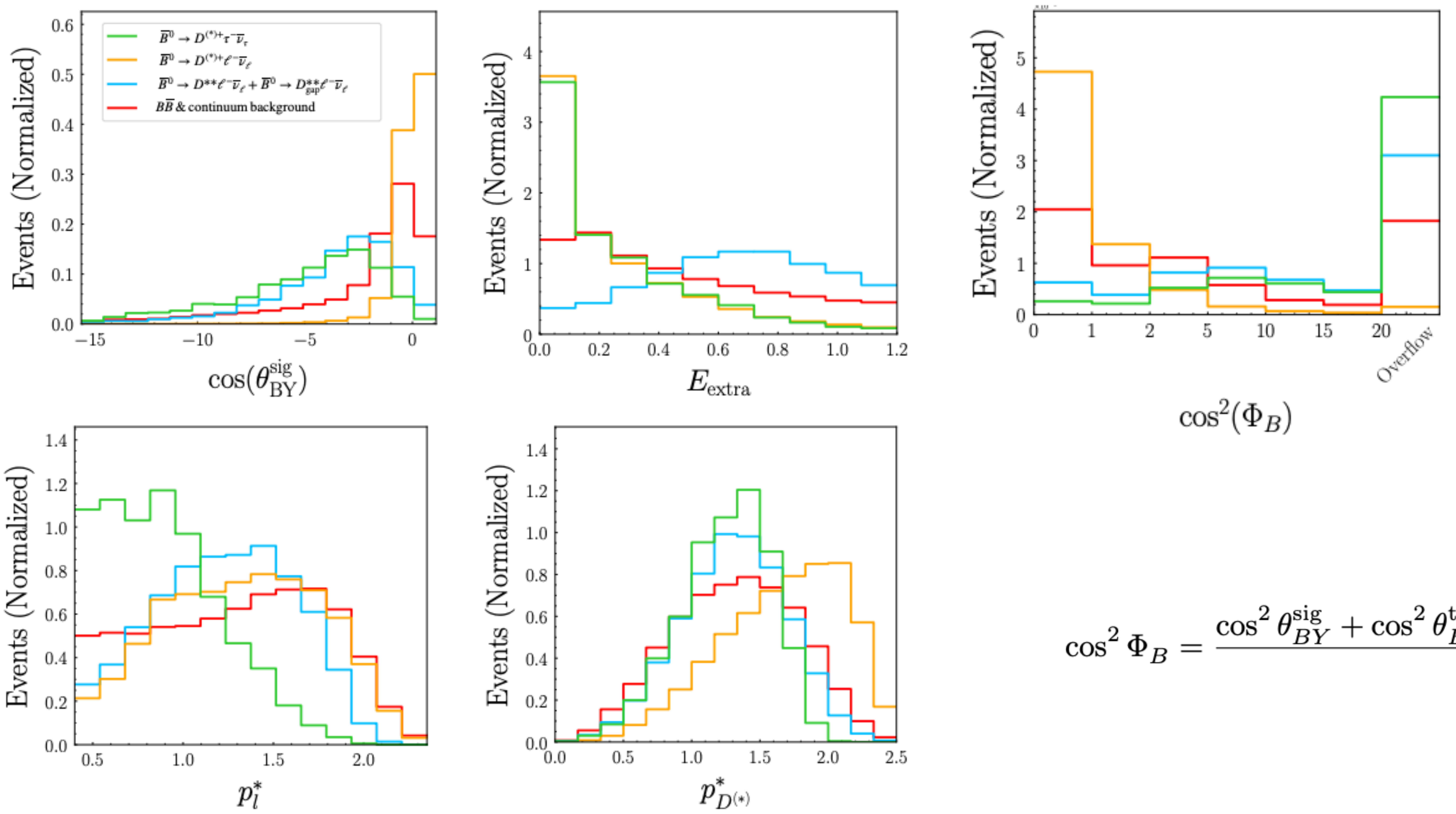
- $\cos\theta_{BY}$ determined from energy-momentum conservation principle and assuming the missing particle is ν ($m_\nu \sim 0$)
- Tha azimuthal angle (ϕ) is unknown
- ϕ can be determined with the constraint that B lies on the cone with an opening angle, θ_{BY} and :
  - Weighted average of 4 possible B-directions about the cone (BaBar)

$R(D^+)$ and $R(D^{*+})$

New To be submitted to Phys. Rev. D

Input variables to BDT

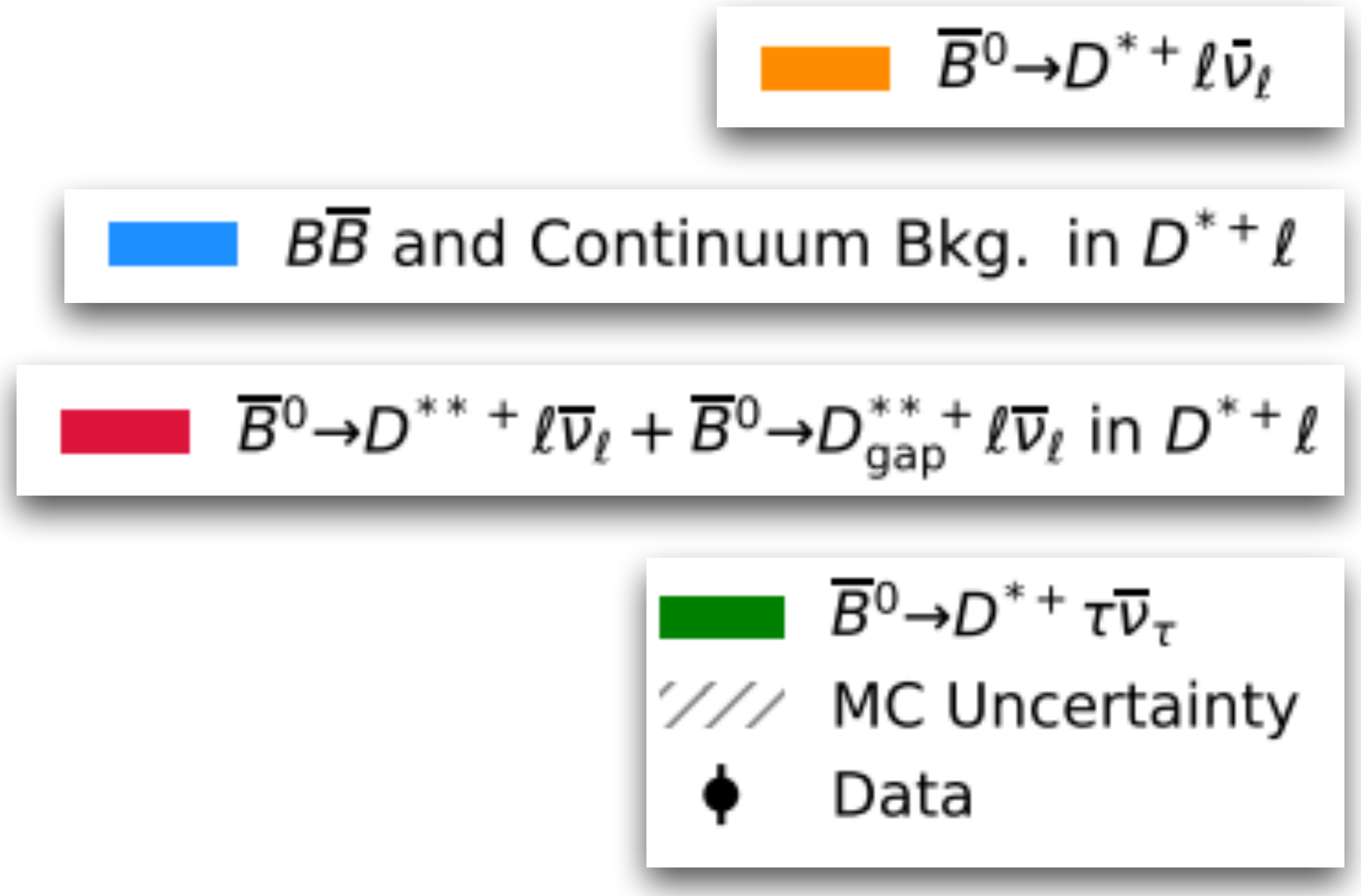
Belle II simulation



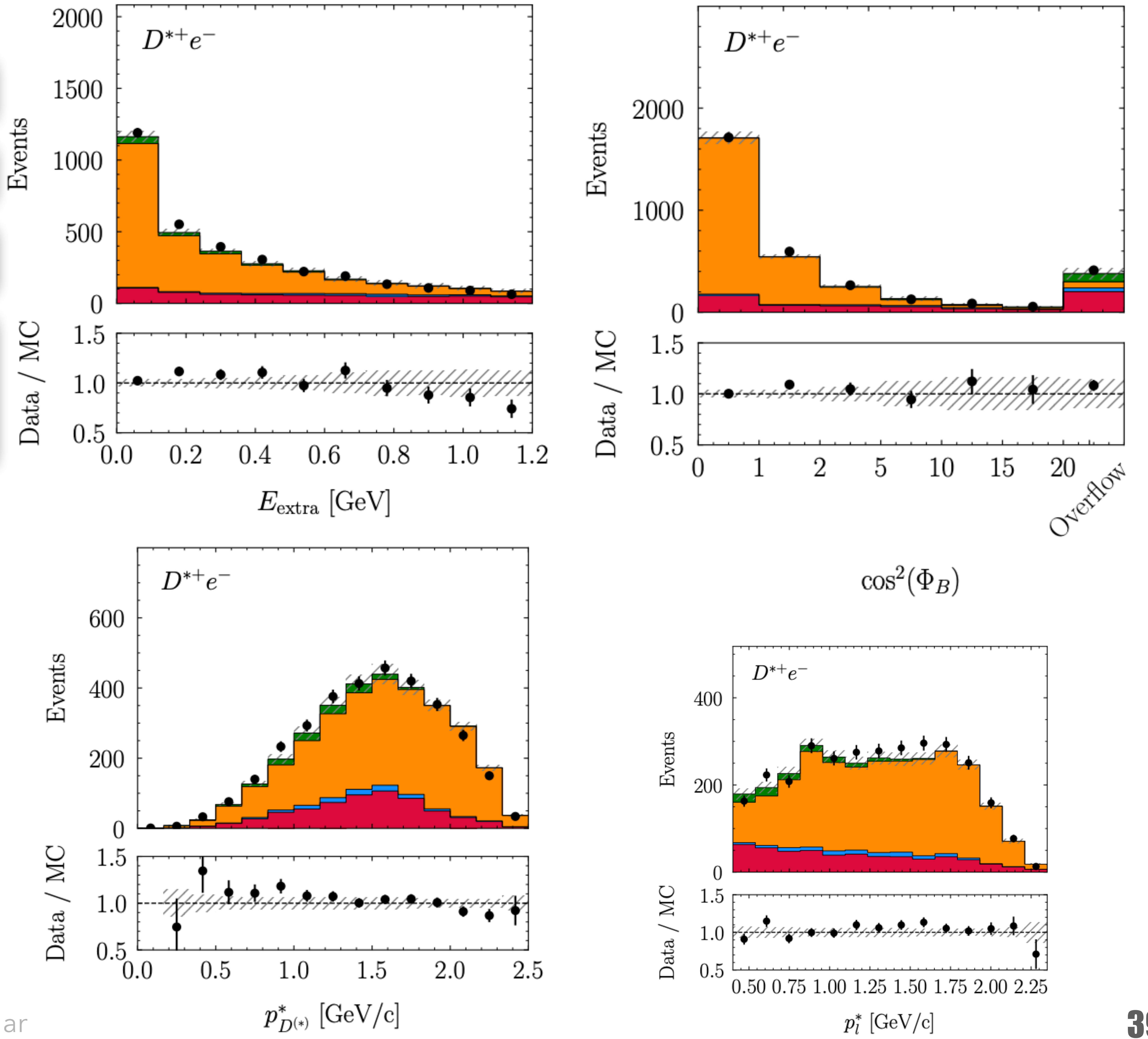
$$\cos^2\Phi_B = \frac{\cos^2\theta_{BY}^{\text{sig}} + \cos^2\theta_{BY}^{\text{tag}} + 2\cos\theta_{BY}^{\text{sig}}\cos\theta_{BY}^{\text{tag}}\cos\gamma}{\sin^2\gamma}$$

$R(D^+)$ and $R(D^{*+})$

Input variables to BDT (data/MC agreements)



$$\cos^2 \Phi_B = \frac{\cos^2 \theta_{BY}^{sig} + \cos^2 \theta_{BY}^{tag} + 2\cos\theta_{BY}^{sig}\cos\theta_{BY}^{tag}\cos\gamma}{\sin^2\gamma}$$



$R(D^+)$ and $R(D^{*+})$

$\mathcal{R}(D^{(*)})$ with light leptons

$$\mathcal{R}(D^+_{e/\mu}) = 1.07 \pm 0.05(\text{stat}) \pm 0.03(\text{syst})$$

$$\mathcal{R}(D^{+*}_{e/\mu}) = 1.08 \pm 0.04(\text{stat}) \pm 0.03(\text{syst})$$

- Results are consistent with LFU expectations within 1.3σ and 2.0σ, respectively

$R(D^+)$ and $R(D^{*+})$

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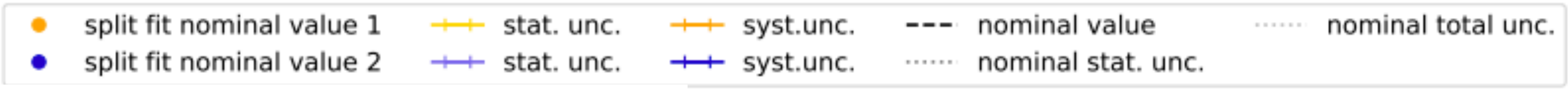
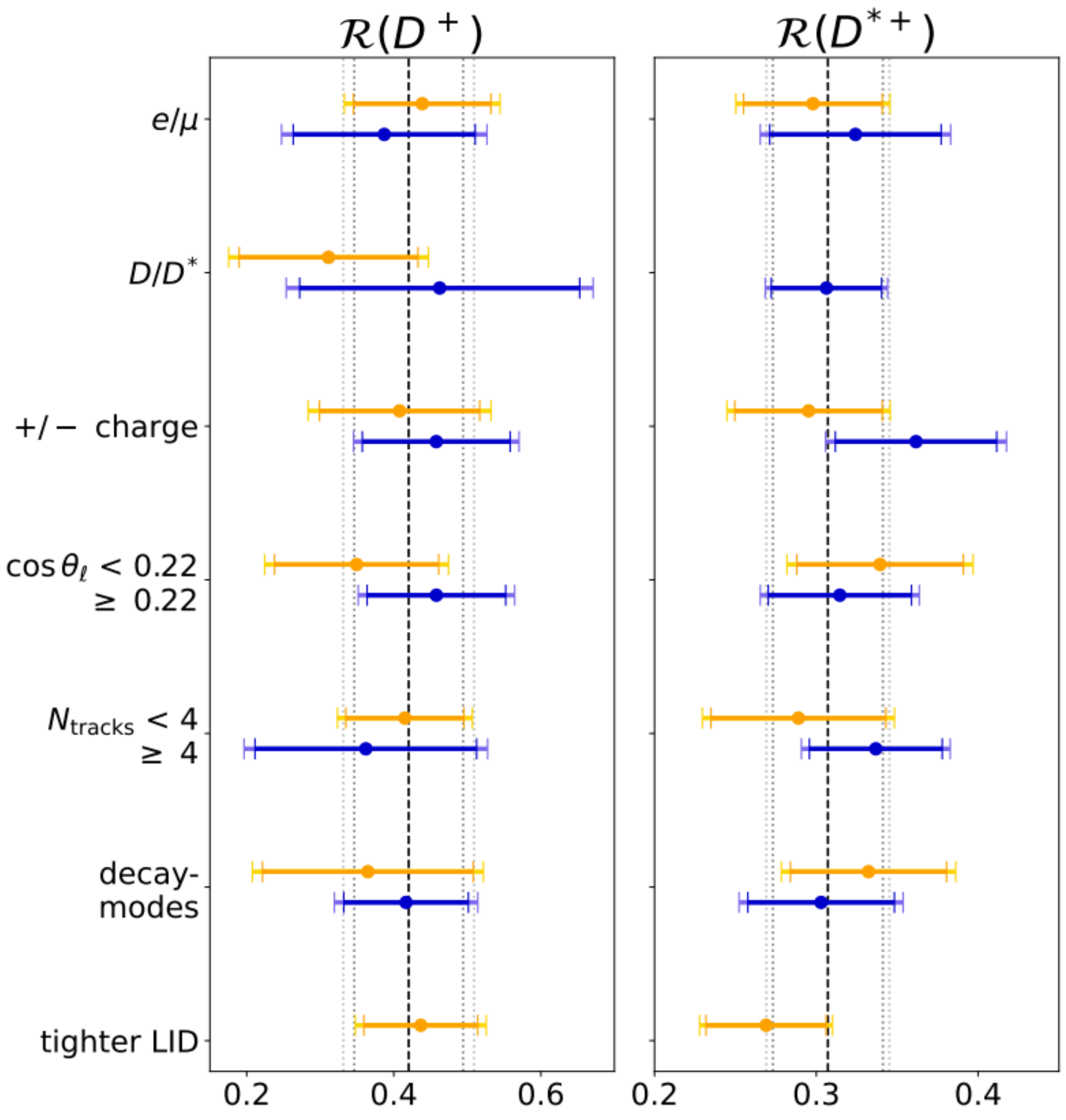
Stability check





$\mathscr{R}(D^{(*)+})$ determined independently for e/μ

$\mathscr{R}(D^{*+})$ from D^+ are due to limited "feed-downs", showing large anti-correlation

Split the sample into approx. two equal halves

D^+ has more $N_{\text{tracks}} < 4$, then D^{*+}

$R(D^+)$ and $R(D^{*+})$

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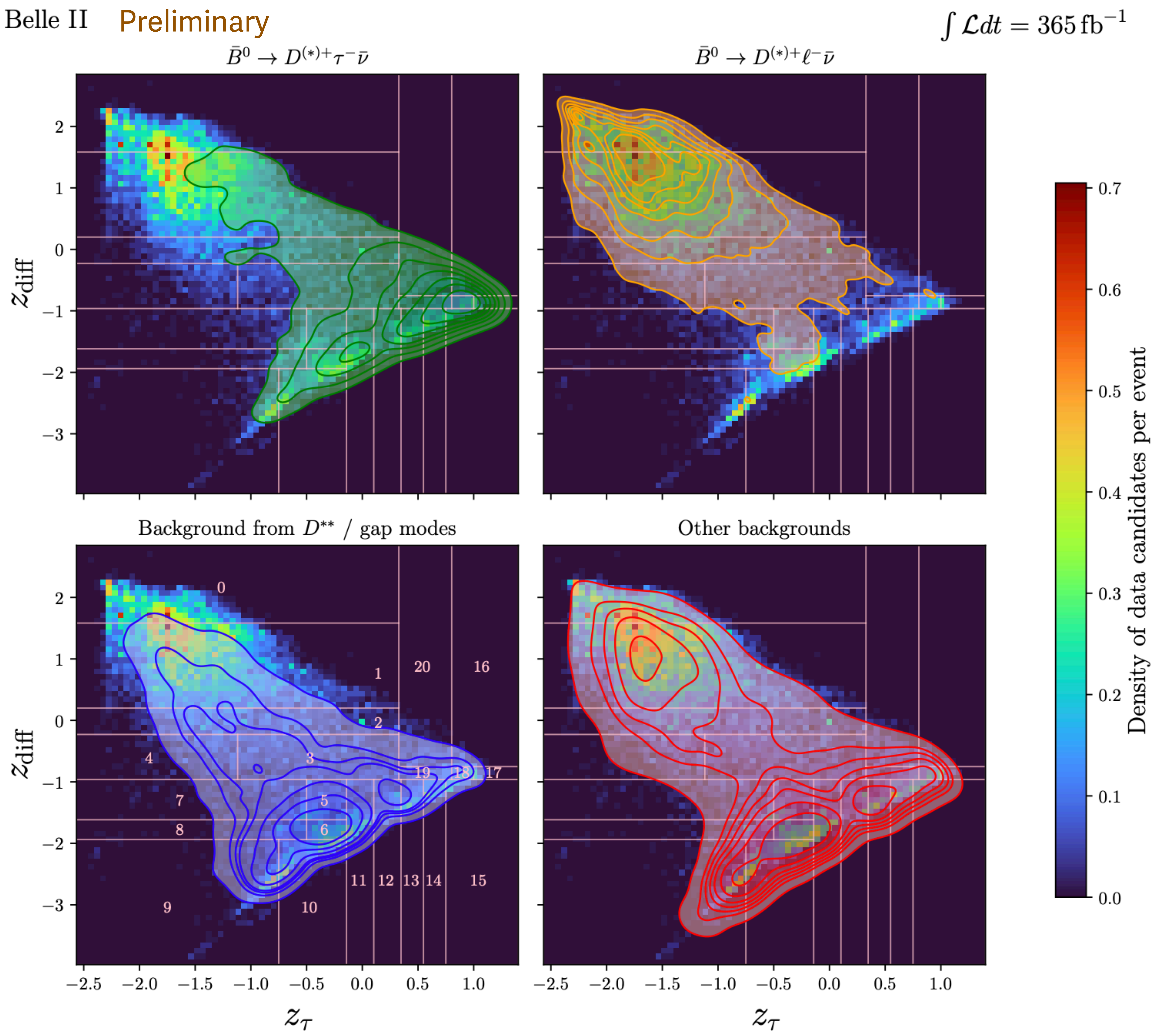

Systematic Uncertainty	$\Delta\mathcal{R}(D^+)$	$\Delta\mathcal{R}(D^{*+})$
Add. & Mult. Uncertainties		
MC sample size	0.032 (7.73 %)	0.0155 (5.05 %)
Additive Uncertainties		
LID efficiency (e)	0.0005 (0.13 %)	0.0001 (0.02 %)
LID efficiency (μ)	0.018 (4.26 %)	0.0010 (0.32 %)
Fake rates (e)	0.0198 (4.71 %)	0.0039 (1.26 %)
Fake rates (μ)	0.0004 (0.09 %)	0.0002 (0.06 %)
BDT modeling	0.0140 (3.4 %)	0.0070 (2.2 %)
Gap Branching fractions	0.010 (2.44 %)	0.0005 (0.2 %)
$\overline{B} \to D^{(*)}\ell\bar{\nu}_\ell$ FFs	0.0022 (0.55 %)	0.0014 (0.45 %)
$\mathcal{B}(\overline{B} \to D^{**}\ell\bar{\nu}_\ell)$	0.0025 (0.60 %)	0.0002 (0.07 %)
$\overline{B} \to D^{**}\ell\bar{\nu}_\ell$ FFs	0.0025 (0.61 %)	0.0007 (0.24%)
Gap Modeling	0.0022 (0.52 %)	0.0007 (0.22 %)
$\pi^\pm$ from $D^* \to D\pi$	0.0003 (0.07%)	0.0003 (0.10 %)
Tracking efficiency	< 0.0001 ($< 0.01\%$)	< 0.0001 ($< 0.01\%$)
Multiplicative Uncertainties		
LID efficiency (e)	0.0007 (0.18 %)	0.0004 (0.12 %)
LID efficiency (μ)	0.023 (5.55 %)	0.0002 (0.08 %)
$\overline{B} \to D^{(*)}\ell\bar{\nu}_\ell$ FFs	0.0012 (0.29 %)	0.004 (1.3 %)
$\mathcal{B}(\tau^- \to \ell^-\bar{\nu}_\ell\nu_\tau)$	0.0006 (0.18 %)	0.0006 (0.18 %)
$\pi^\pm$ from $D^* \to D\pi$	0.0002 (0.04%)	0.0004 (0.13%)
Tracking efficiency	< 0.0001 ($< 0.01\%$)	0.0001 (0.04 %)
Total Syst. Uncertainty	0.051 (12.32%)	0.018 (5.88%)

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

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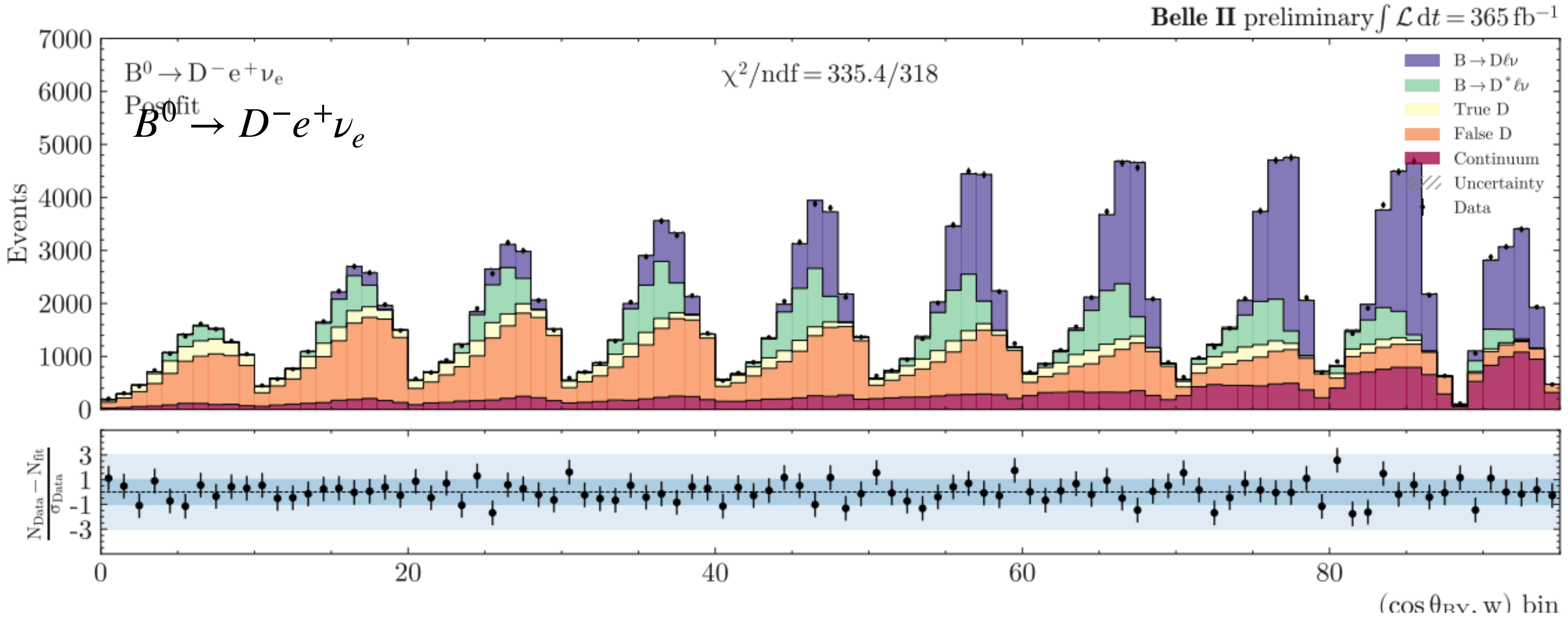
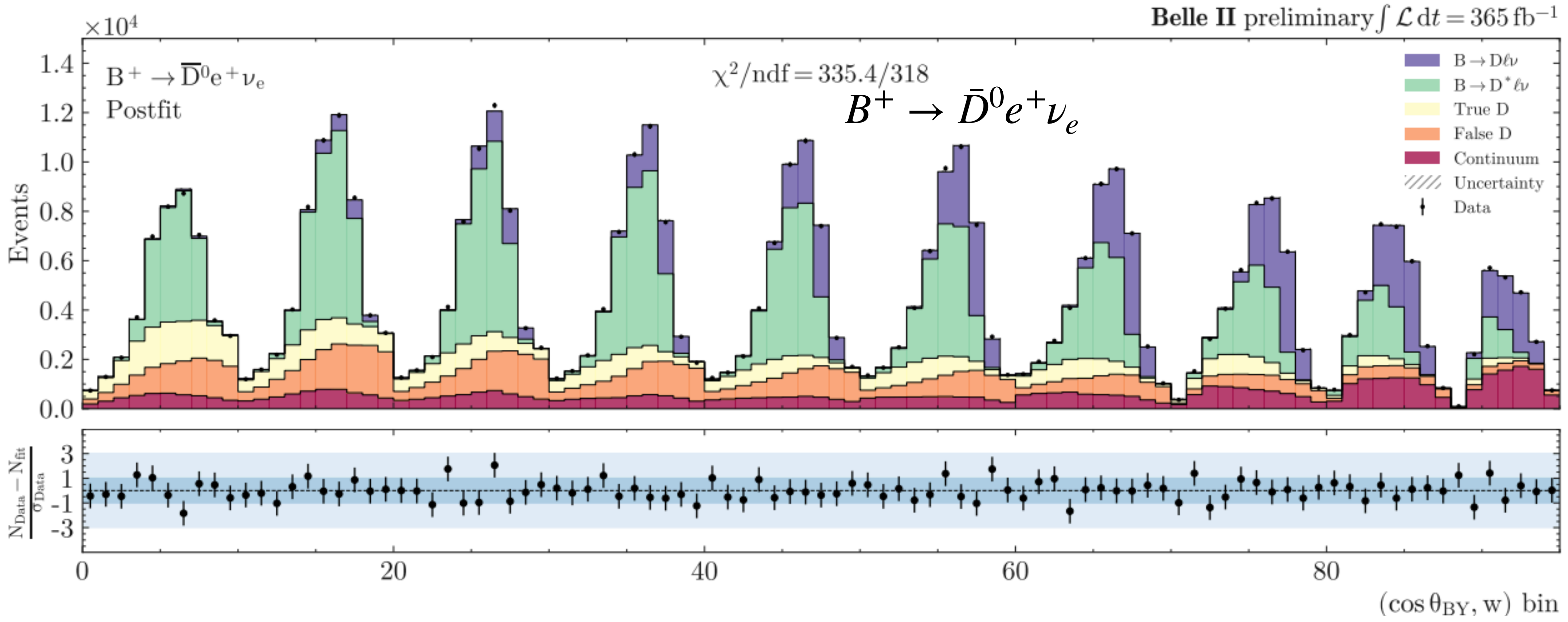
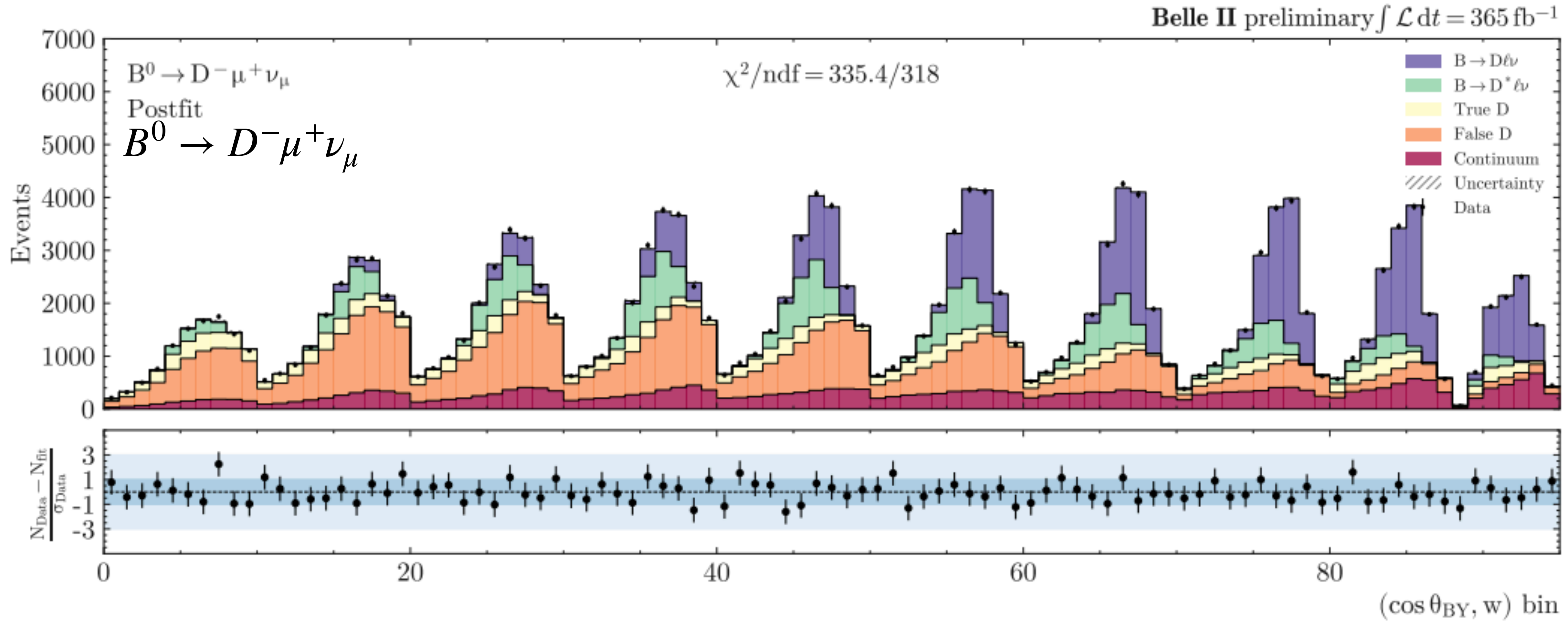
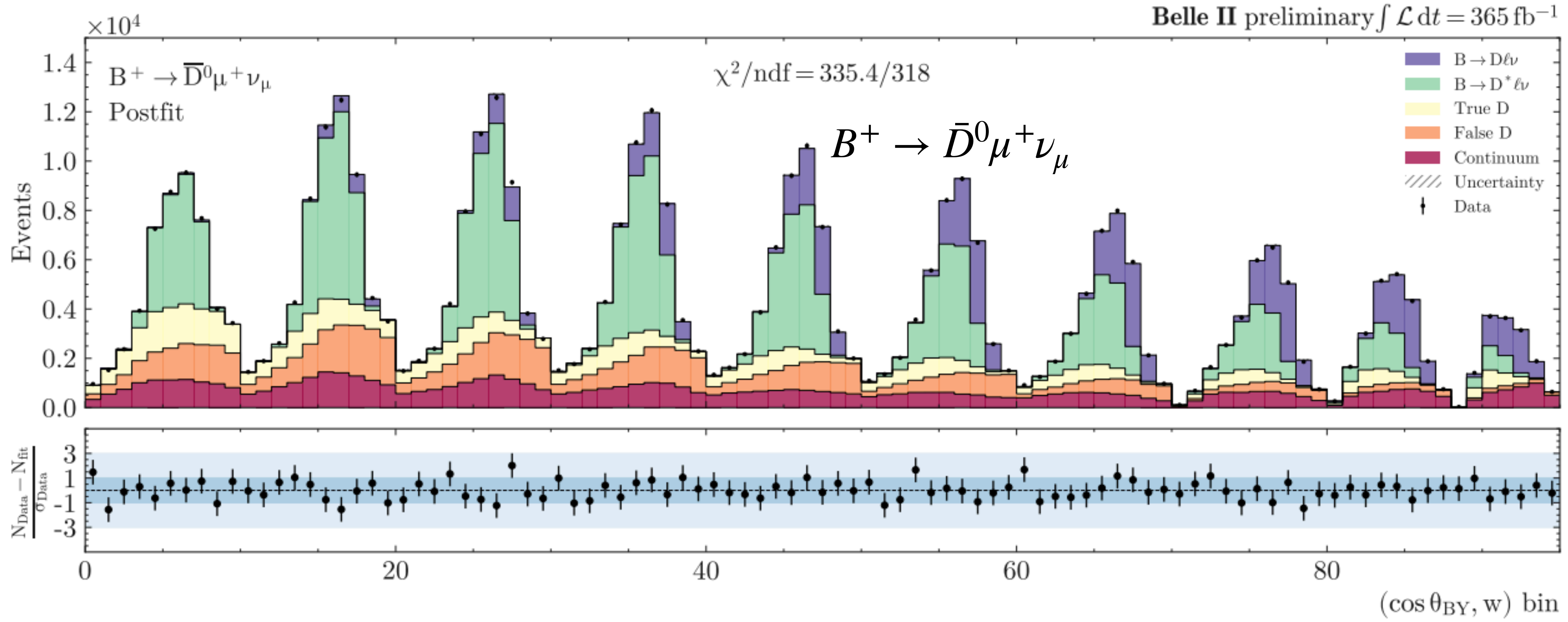
Signal extraction









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

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	Signal Yield	$\mathcal{B}$ [%]
$B^+ \to \bar{D}^0 e^+ \nu_e$	75,186	2.34 ± 0.11
$B^+ \to \bar{D}^0 \mu^+ \nu_\mu$	61,259	2.27 ± 0.11
$B^0 \to D^- e^+ \nu_e$	47,617	2.07 ± 0.13
$B^0 \to D^- \mu^+ \nu_\mu$	39,648	2.05 ± 0.13
$B^0 \to D^- \ell^+ \nu_\ell$		2.06 ± 0.12
$B^+ \to \bar{D}^0 \ell^+ \nu_\ell$		2.31 ± 0.10
$B \to D\ell\nu$		2.10 ± 0.08

$|V_{cb}|$ is extracted using χ^2 fits to the measured w spectra

CLN parametrisation of the FF

$$\chi^2 = \sum_{i,j} \left(\frac{\Delta\Gamma_i}{\Delta w} - \frac{\Delta\Gamma_{i,\mathrm{CLN}}}{\Delta w} \right) C_{ij}^{-1} \left(\frac{\Delta\Gamma_j}{\Delta w} - \frac{\Delta\Gamma_{j,\mathrm{CLN}}}{\Delta w} \right)$$

Result (Preliminary)

$$\eta_{\mathrm{EW}} \mathcal{G}(1) |V_{cb}| = (40.9 \pm 1.4) \times 10^{-3}$$
$$\rho^2 = 1.09 \pm 0.06 \,,$$

$$|V_{cb}|_{\mathrm{CLN}} = (38.5 \pm 1.3) \times 10^{-3}$$

Source		Uncertainty [%]
Statistical		0.9
Systematic		1.5
	MC Stat. Error	0.5
	N_{bb}	0.5
	f_{00}/f_{+-}	0.1
	$f_{\not{B}}$	0.3
	$\mathcal{B}(D \to K\pi(\pi))$	0.3
	Vertex fit χ^2 correction	0.5
	$\mathcal{B}(B \to X_c \ell \nu_\ell)$	0.3
	Lepton identification	0.2
	Kaon identification	0.5
	Tracking efficiency	0.3
	Signal PDF	0.4
	$B \to D^* \ell \nu_\ell$ form factor	0.1
	Background w modelling	0.5
	$E^*_Y - m_Y$ reweighing	0.3
	$B^{0/-}$ lifetime	0.1
Theoretical (FF fits)		1.3
	Lattice QCD inputs	1.2
	Long-distance QED	0.4
Total		2.1

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

New

To be submitted to Phys. Rev. D

Belle II

$\Delta\Gamma_i/\Delta w$ and the correlations across different bins combined for the 4 sub-samples

i	$w_{i,\min}$	$w_{i,\max}$	$\Delta\Gamma_i/\Delta w[10^{-15}\text{GeV}]$	ρ_{ij} 1	2	3	4	5	6	7	8	9	10
1	1.00	1.06	0.22 ± 0.59	1.00	-0.06	0.15	0.08	0.07	0.04	0.03	0.02	0.00	-0.00
2	1.06	1.12	3.54 ± 0.56		1.00	0.13	0.33	0.26	0.24	0.22	0.19	0.13	0.07
3	1.12	1.18	6.46 ± 0.61			1.00	0.25	0.44	0.37	0.36	0.31	0.22	0.13
4	1.18	1.24	10.17 ± 0.68				1.00	0.37	0.59	0.52	0.48	0.34	0.20
5	1.24	1.30	14.27 ± 0.72					1.00	0.49	0.67	0.55	0.41	0.23
6	1.30	1.36	18.68 ± 0.84						1.00	0.58	0.71	0.49	0.30
7	1.36	1.42	21.41 ± 0.89							1.00	0.59	0.60	0.36
8	1.42	1.48	25.42 ± 0.96								1.00	0.49	0.48
9	1.48	1.54	28.11 ± 1.09									1.00	0.61
10	1.54	$w_{\max}$	29.44 ± 1.41										1.00

$\Delta\Gamma_i/\Delta w$ for the 4 sub-samples

			$\Delta\Gamma_i/\Delta w\ [10^{-15}\text{GeV}]$			
i	$w_{i,\min}$	$w_{i,\max}$	$B^0 \to D^- e^+ \nu_e$	$B^0 \to D^- \mu^+ \nu_\mu$	$B^+ \to \bar{D}^0 e^+ \nu_e$	$B^+ \to \bar{D}^0 \mu^+ \nu_\mu$
1	1.00	1.06	-0.1 ± 0.7	0.6 ± 0.7	-0.5 ± 1.5	1.8 ± 1.7
2	1.06	1.12	3.7 ± 0.8	3.2 ± 0.8	4.1 ± 1.3	3.7 ± 1.4
3	1.12	1.18	6.2 ± 0.8	7.2 ± 0.9	5.5 ± 1.3	6.1 ± 1.2
4	1.18	1.24	9.8 ± 0.9	11.0 ± 0.9	8.9 ± 1.3	10.3 ± 1.4
5	1.24	1.30	13.9 ± 1.0	14.8 ± 1.0	14.0 ± 1.3	13.7 ± 1.3
6	1.30	1.36	18.8 ± 1.2	18.0 ± 1.1	18.6 ± 1.4	18.6 ± 1.5
7	1.36	1.42	21.9 ± 1.2	23.0 ± 1.3	19.6 ± 1.6	19.7 ± 1.6
8	1.42	1.48	25.5 ± 1.4	25.0 ± 1.5	25.5 ± 1.7	25.5 ± 1.8
9	1.48	1.54	29.1 ± 1.7	27.3 ± 1.9	28.1 ± 1.8	26.0 ± 1.9
10	1.54	$w_{\max}$	32.2 ± 2.5	25.3 ± 2.6	30.5 ± 2.3	27.2 ± 2.5