NEW SEMILEPTONIC $B \to X_{c/u} l \nu$ RESULTS AT e^+e^- EXPERIMENTS

Svenja Granderath (University of Bonn)

on behalf of the Belle II collaboration

(with material from the Belle collaboration)

FPCP 2023 - Lyon - May 29, 2023

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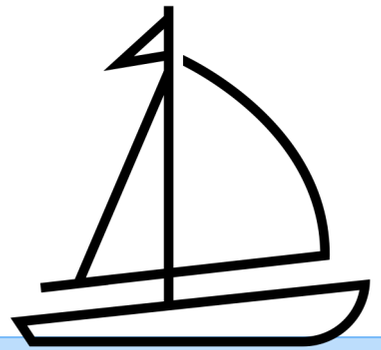
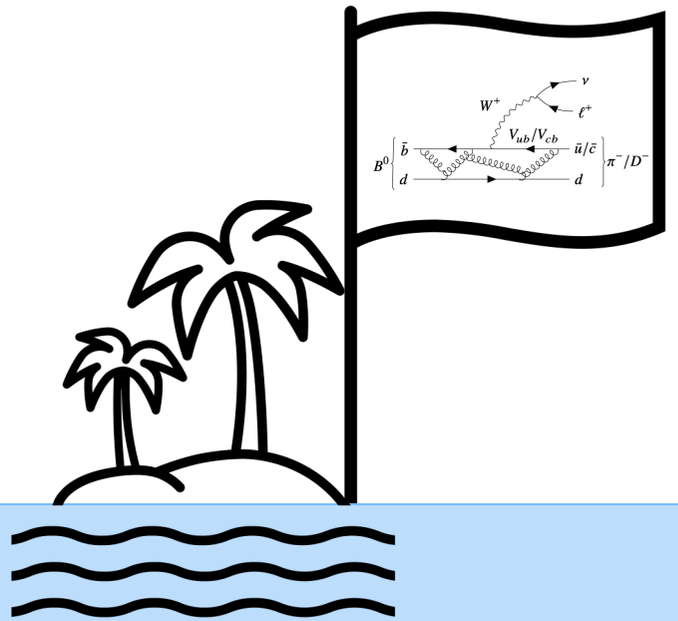
SEMILEPTONIC B DECAYS





Land of semileptonic B decays

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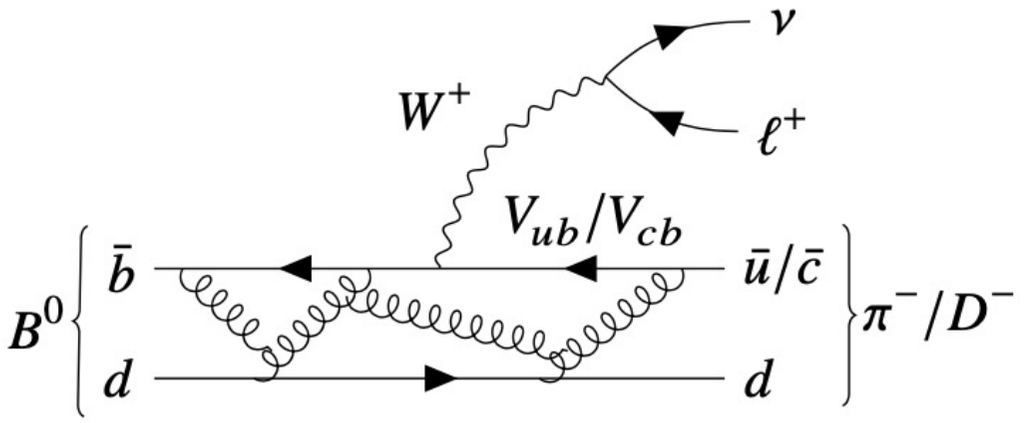
SEMILEPTONIC B DECAYS



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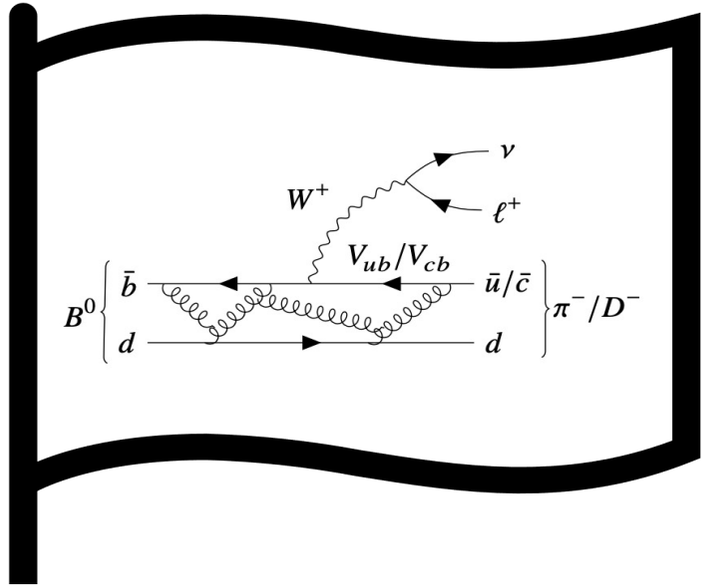
SEMILEPTONIC B DECAYS



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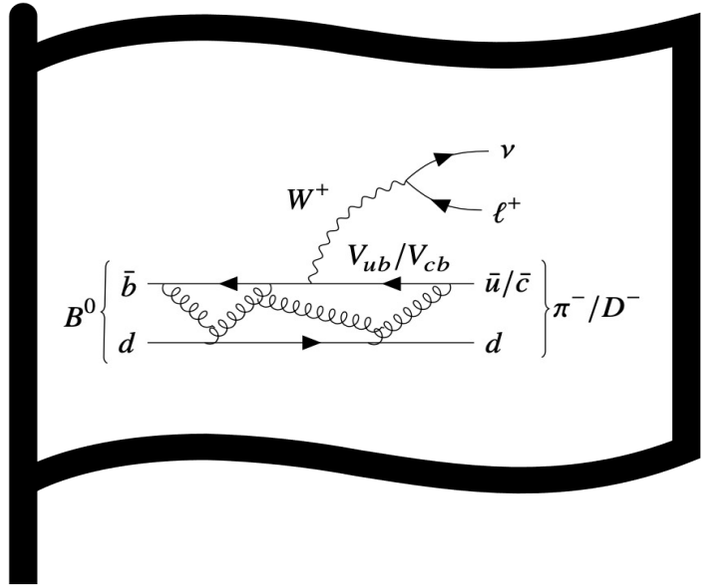
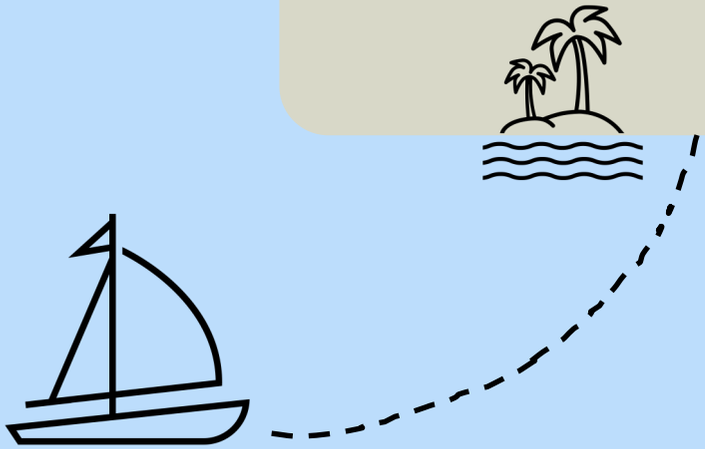


$$\underbrace{\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}}_{\text{CKM Matrix}}$$

Form-factor measurements

SM precision measurements



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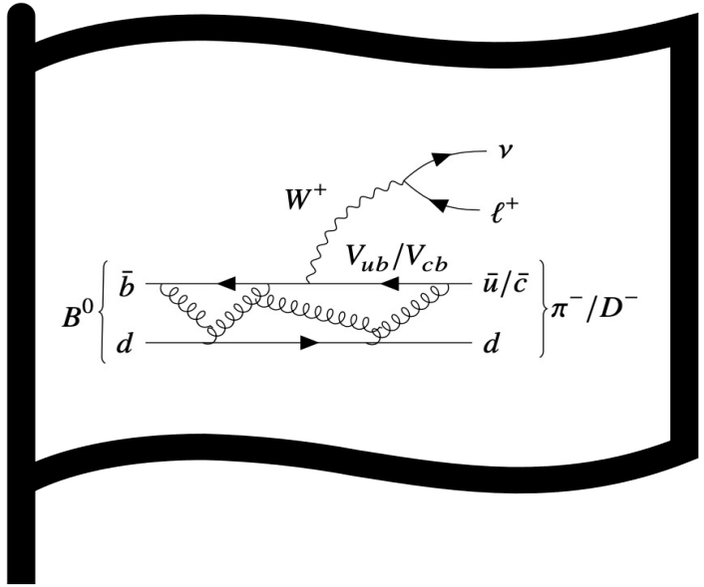
SEMILEPTONIC B DECAYS



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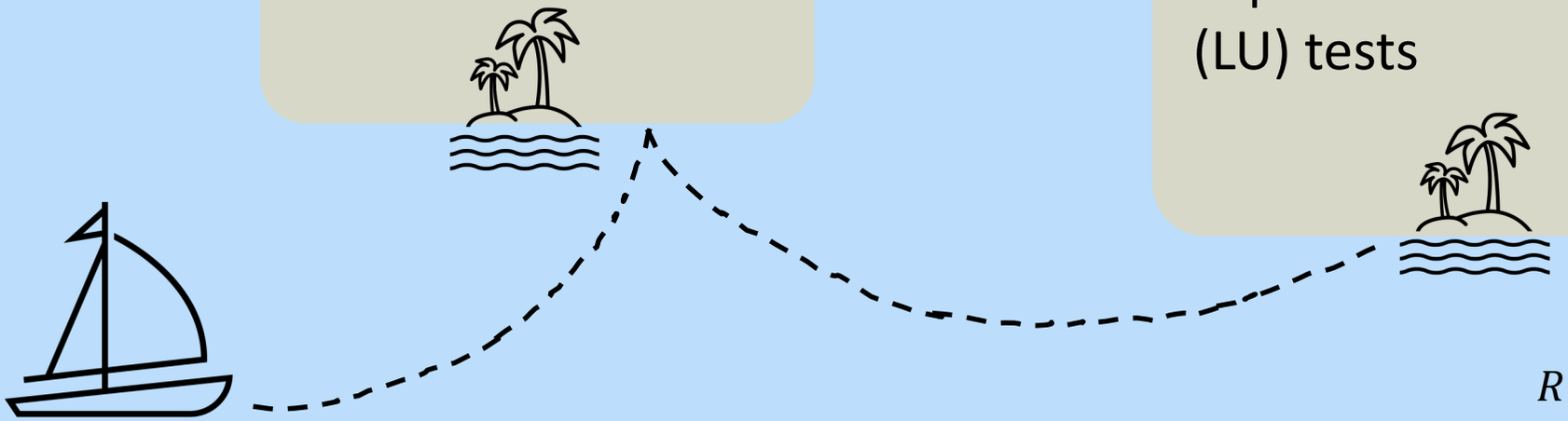
Form-factor measurements

SM precision measurements

Lepton universality (LU) tests

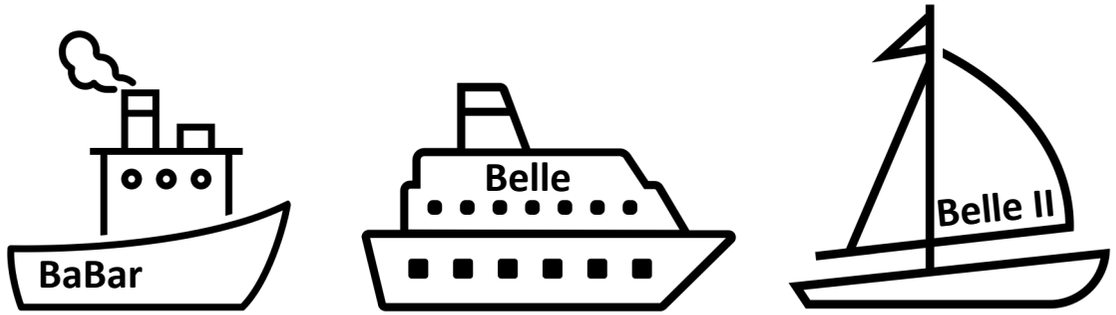
Angular observables



$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(\mathrm{B} \to D^{(*)}l\nu)}$$

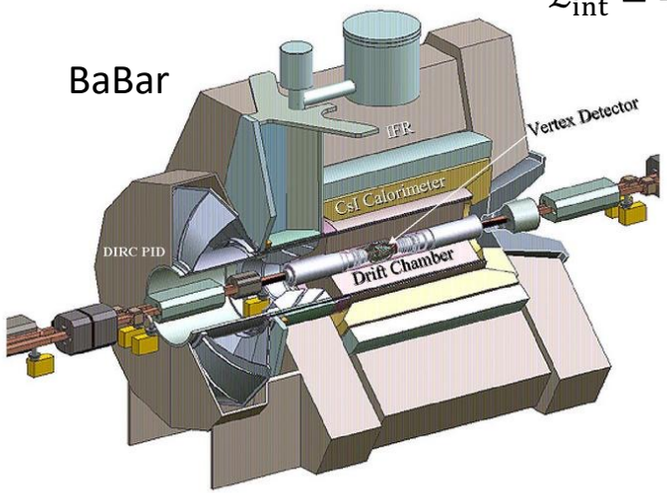
B-FACTORY EXPERIMENTS

- BaBar, Belle and Belle II
- Detectors located at the interaction points of electron-positron colliders
- Center-of-mass energy corresponding to $\Upsilon(4S)$ resonance

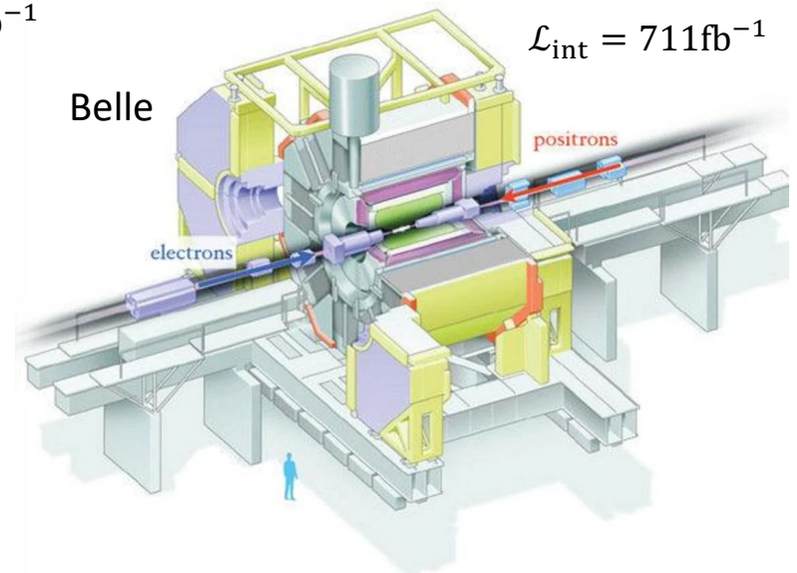


$$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$$

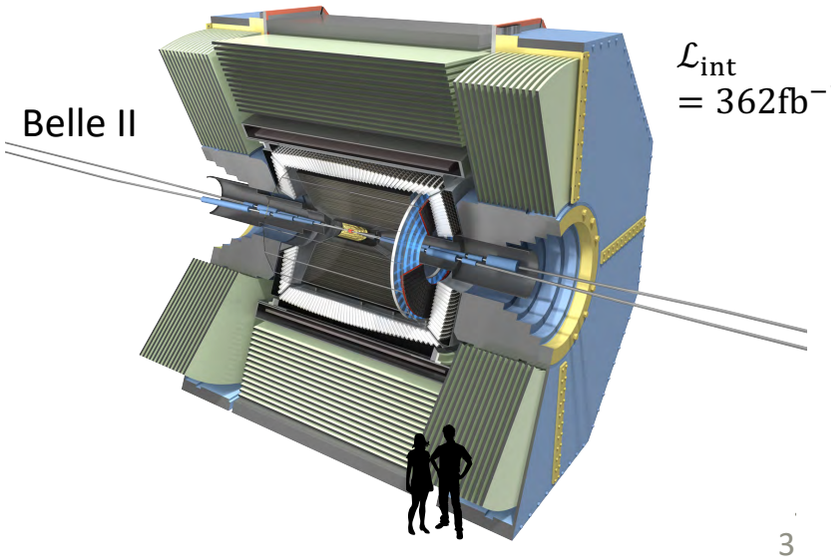
BaBar $\mathcal{L}_{\text{int}} = 433\text{fb}^{-1}$



Belle $\mathcal{L}_{\text{int}} = 711\text{fb}^{-1}$

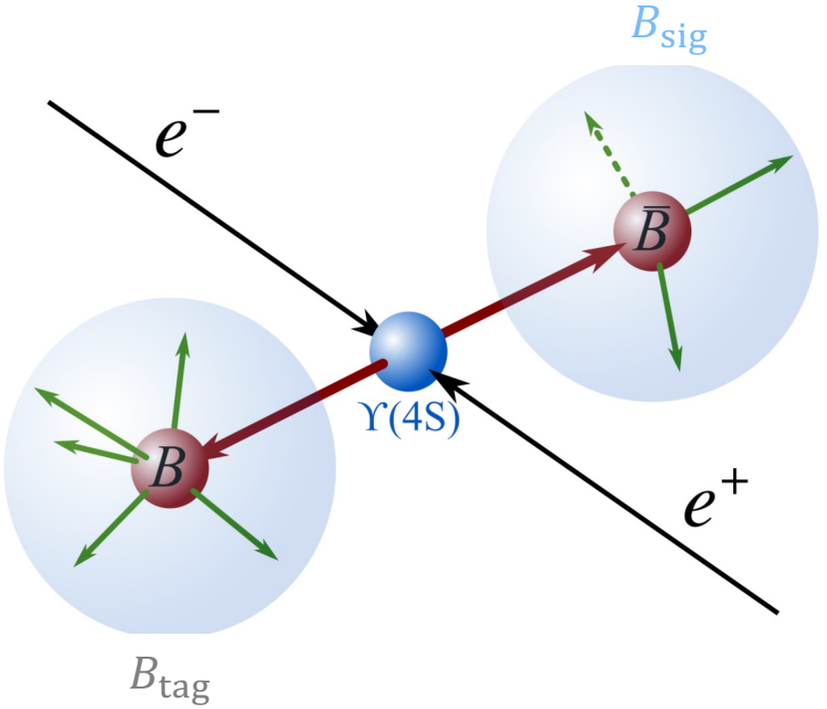


Belle II $\mathcal{L}_{\text{int}} = 362\text{fb}^{-1}$



RECONSTRUCTION: TAGGING

$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B_{\text{sig}}B_{\text{tag}}$



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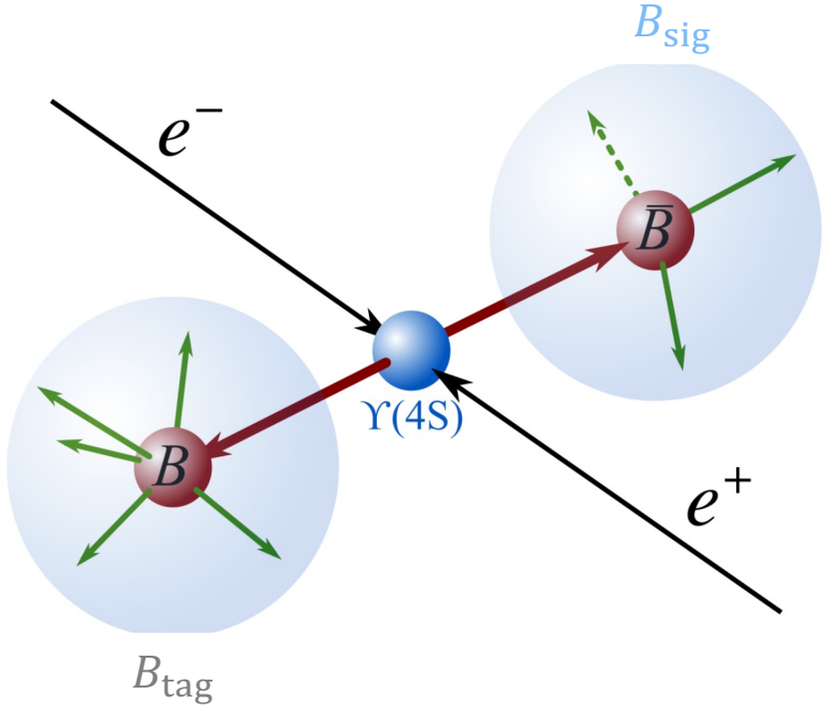

Tagged:

- B_{sig} and B_{tag} reconstructed
- Reconstruct B_{tag} in hadronic or semileptonic modes
- Using multivariate methods

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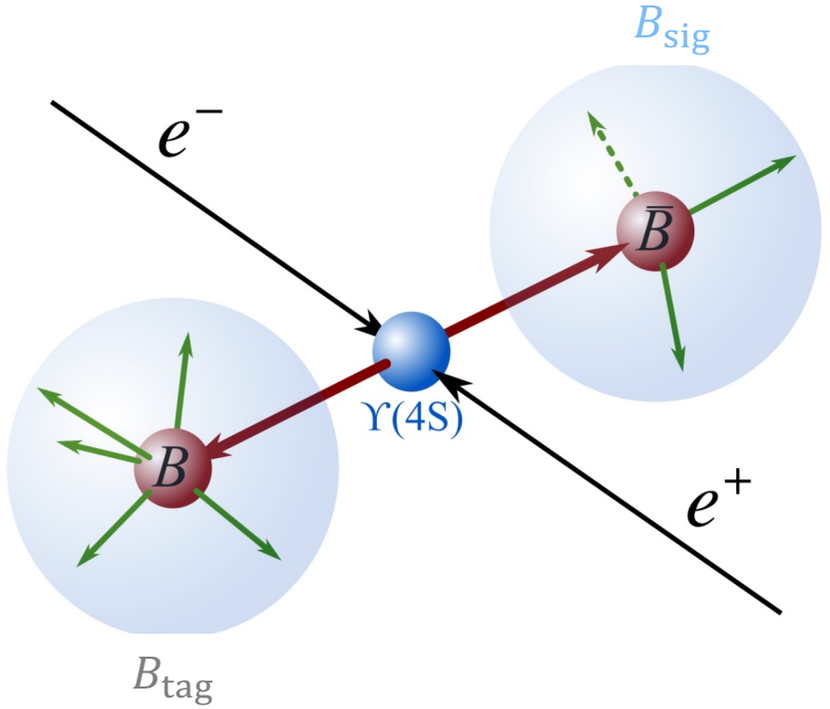

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- Only B_{sig} reconstructed

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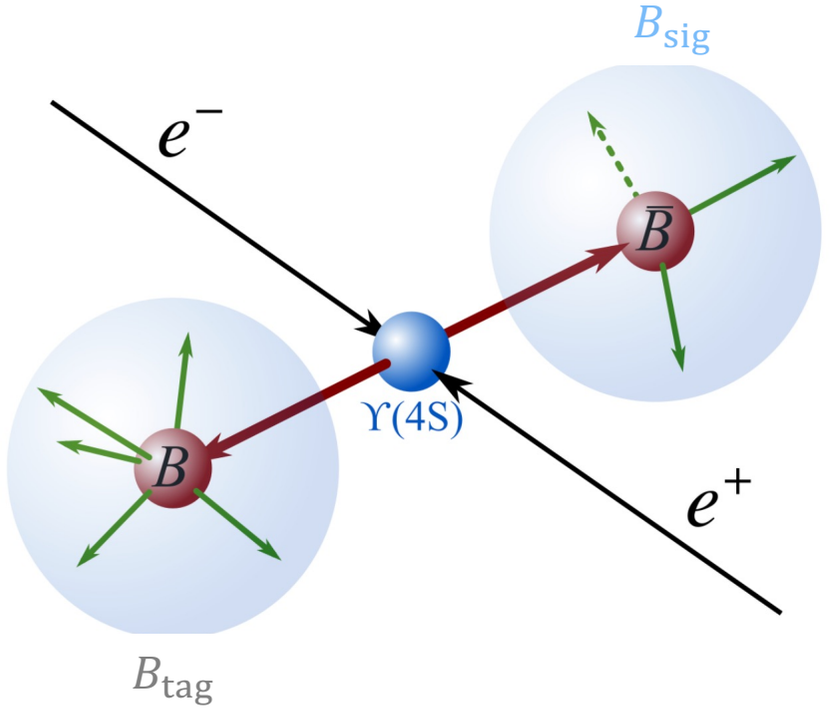

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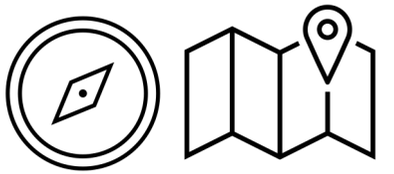
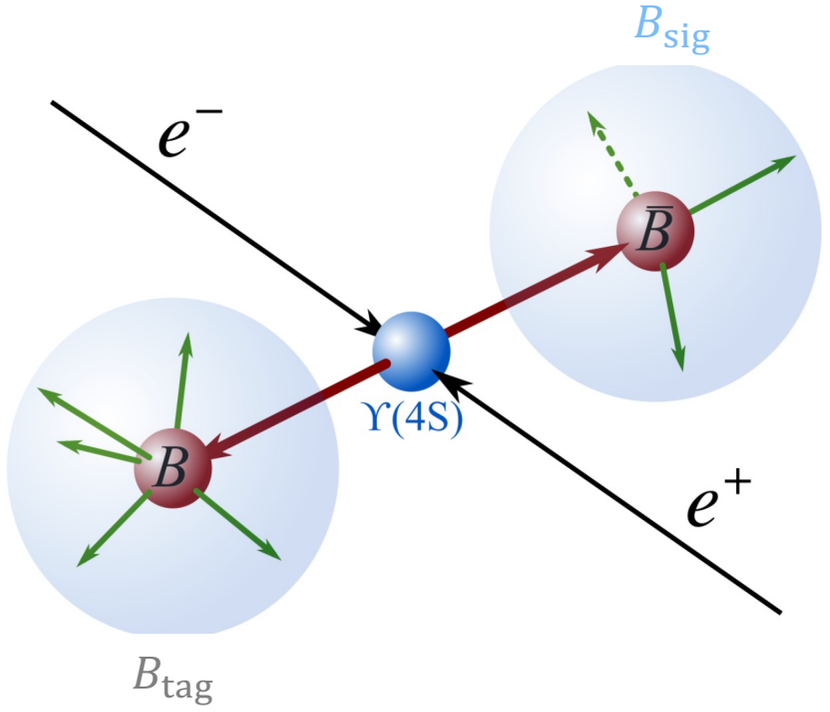


RECONSTRUCTION: EXCLUSIVE/INCLUSIVE

$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B_{\text{sig}}B_{\text{tag}}$



$B \rightarrow D^*lv$ $B \rightarrow Dlv$ $B \rightarrow D^*lv$
$B \rightarrow D^*lv$ $B \rightarrow Dlv$ $B \rightarrow Dlv$
$B \rightarrow Dlv$ $B \rightarrow X_clv$ $B \rightarrow Dlv$
$B \rightarrow X_clv$ $B \rightarrow Dlv$ $B \rightarrow X_clv$
$B \rightarrow D^*lv$
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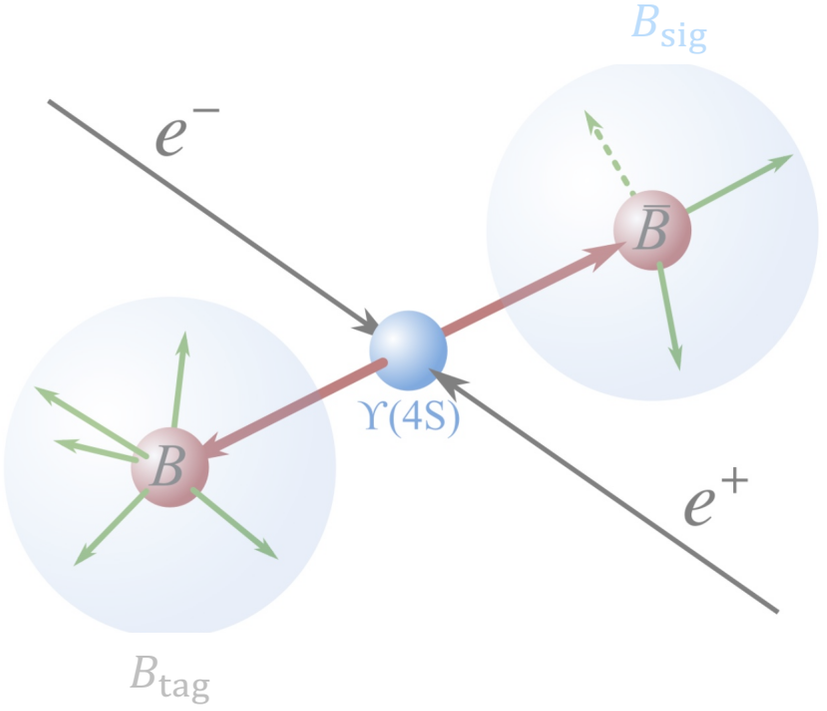
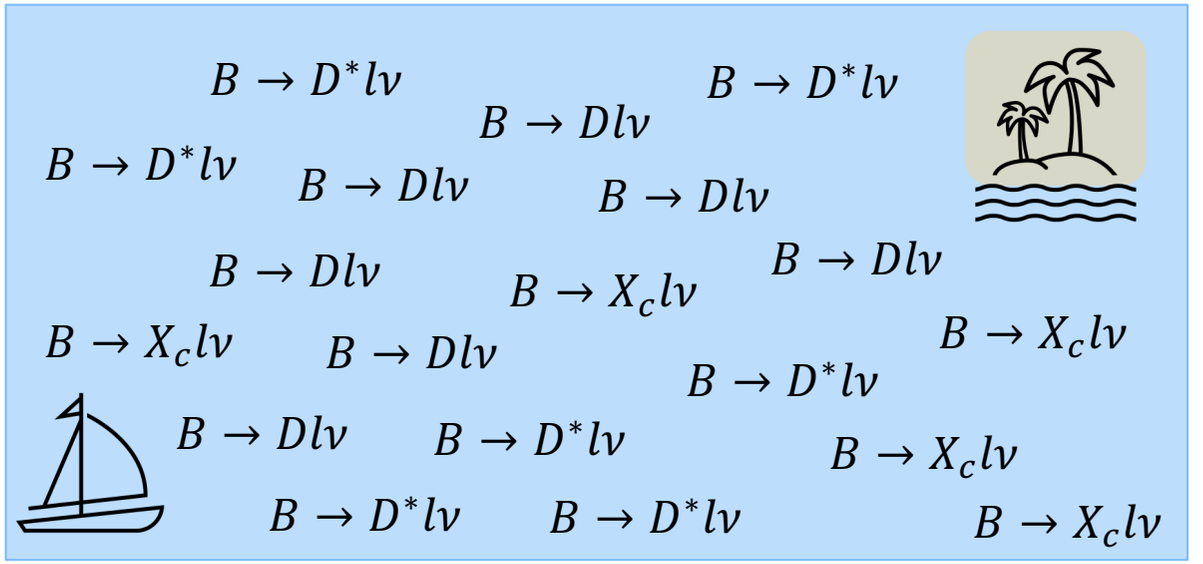


Exclusive:

- B_{sig} reconstructed as specific final state

Inclusive:

- B_{sig} reconstructed as sum of modes



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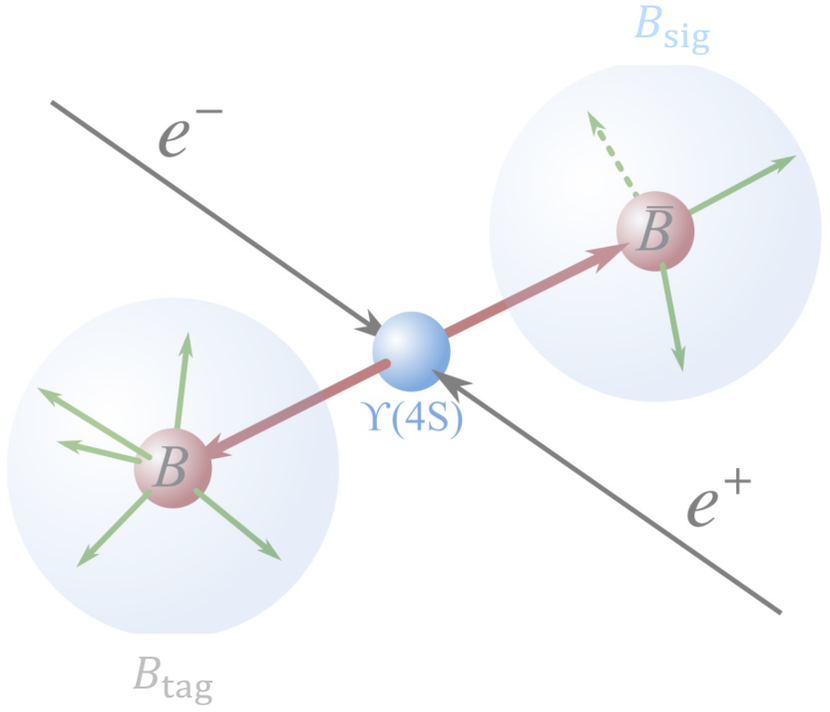

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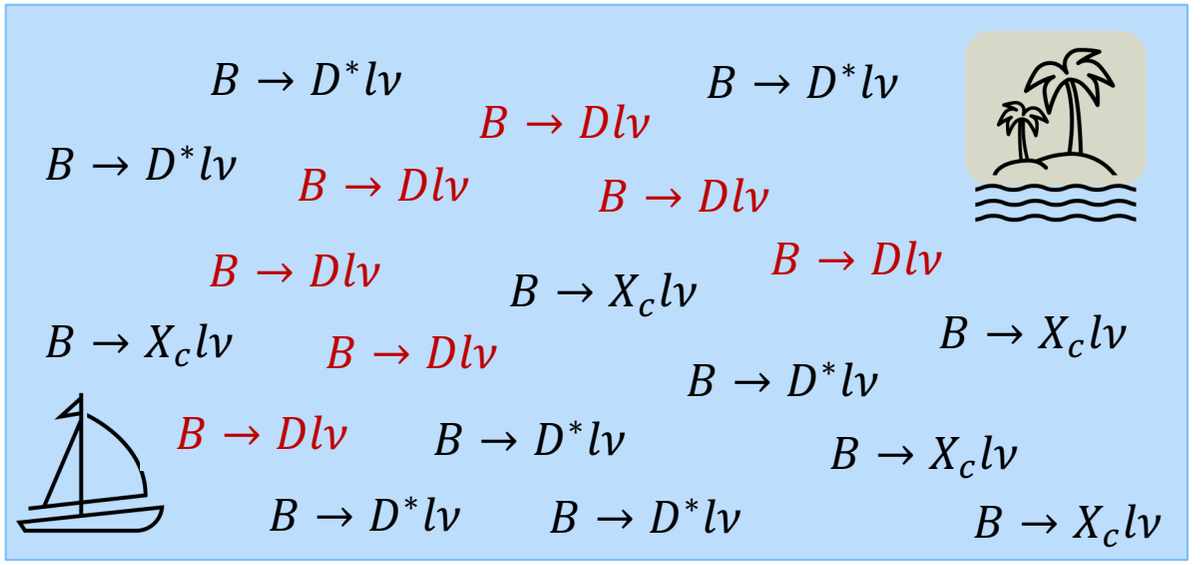

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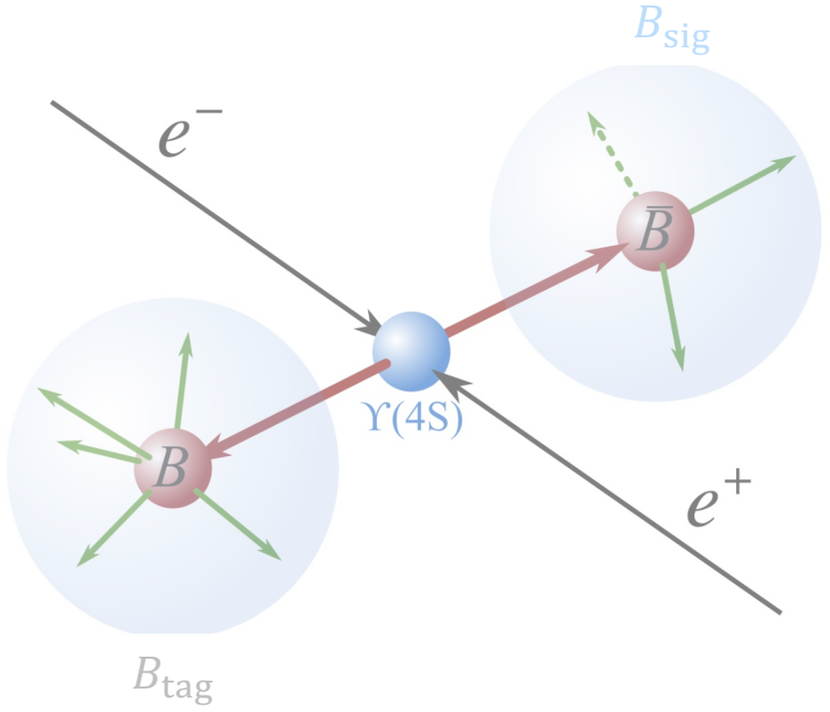

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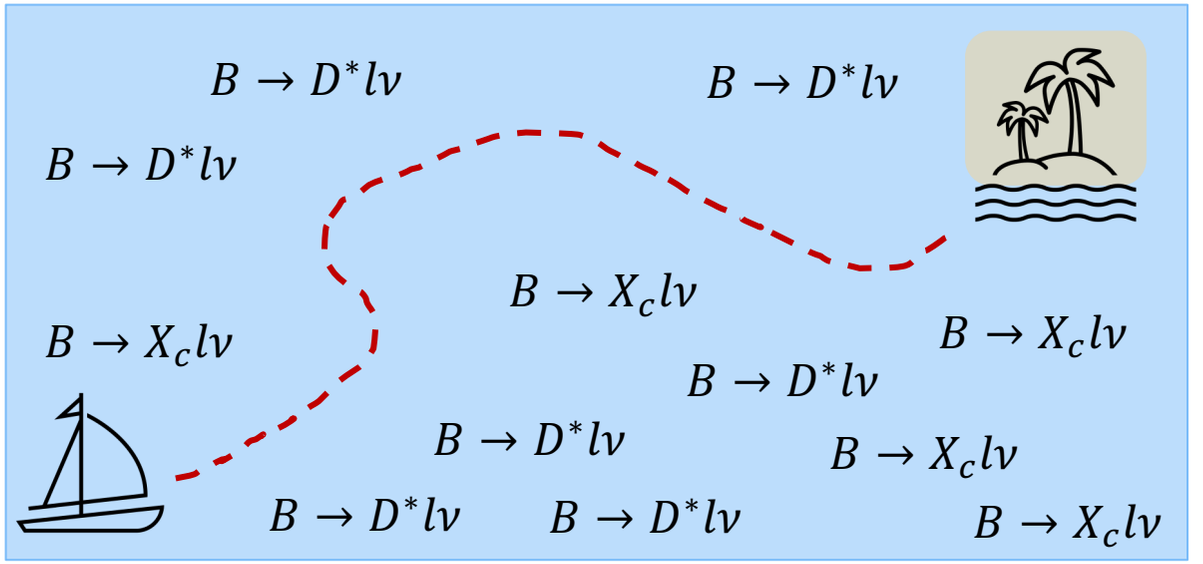

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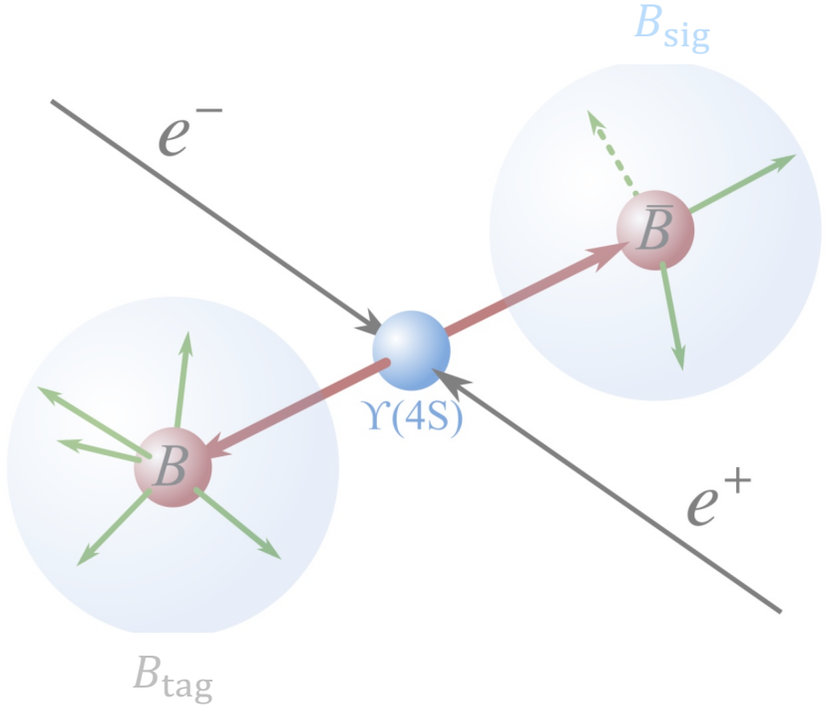

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$B \rightarrow D^* l\nu$ $B \rightarrow Dl\nu$ $B \rightarrow D^* l\nu$ $B \rightarrow Dl\nu$ $B \rightarrow D^* l\nu$ $B \rightarrow Dl\nu$ $B \rightarrow Dl\nu$ $B \rightarrow X_c l\nu$ $B \rightarrow Dl\nu$ $B \rightarrow X_c l\nu$ $B \rightarrow Dl\nu$ $B \rightarrow D^* l\nu$ $B \rightarrow Dl\nu$ $B \rightarrow D^* l\nu$ $B \rightarrow X_c l\nu$ $B \rightarrow D^* l\nu$ $B \rightarrow D^* l\nu$ $B \rightarrow X_c l\nu$

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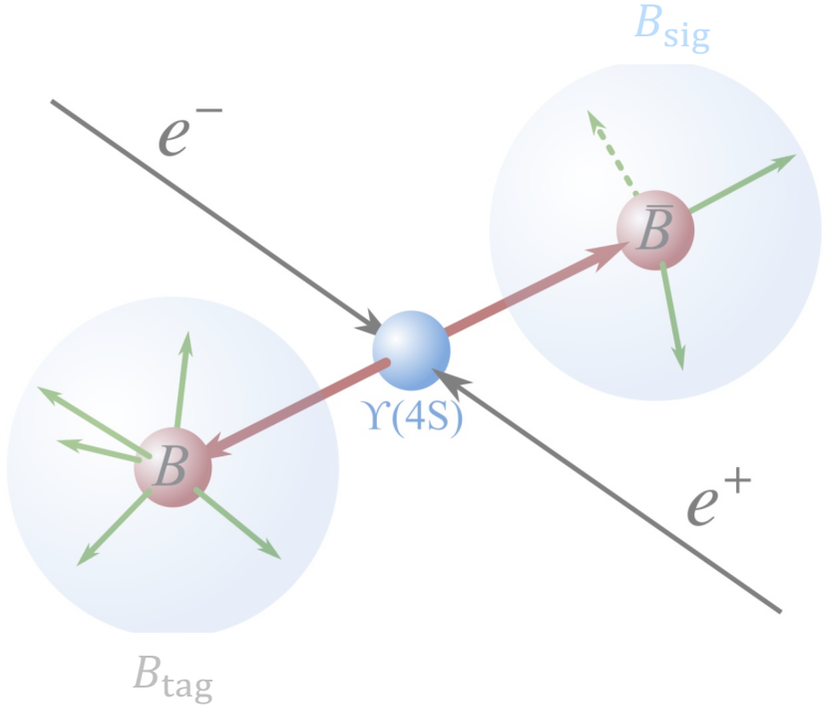
$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B_{\text{sig}}B_{\text{tag}}$



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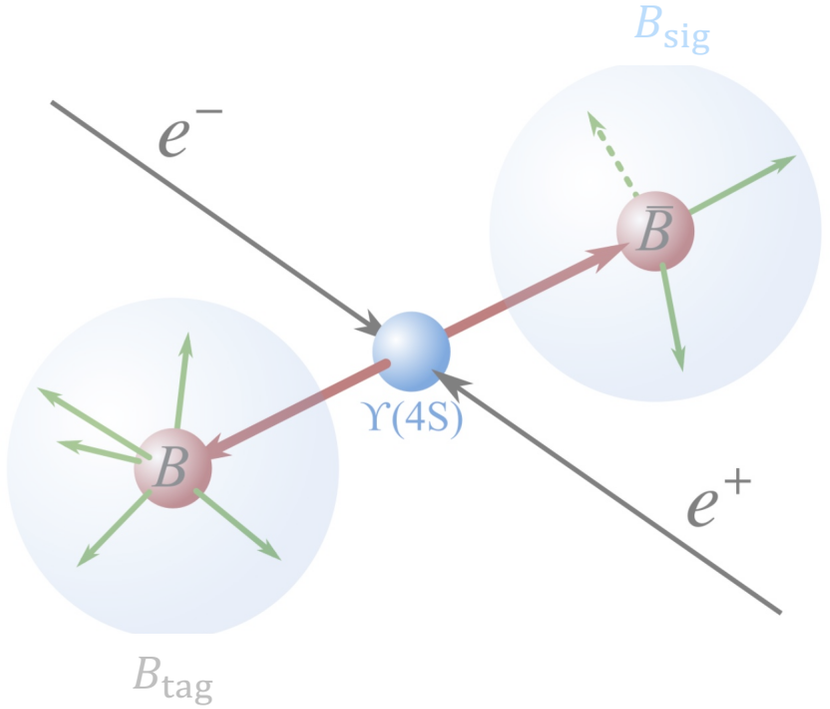

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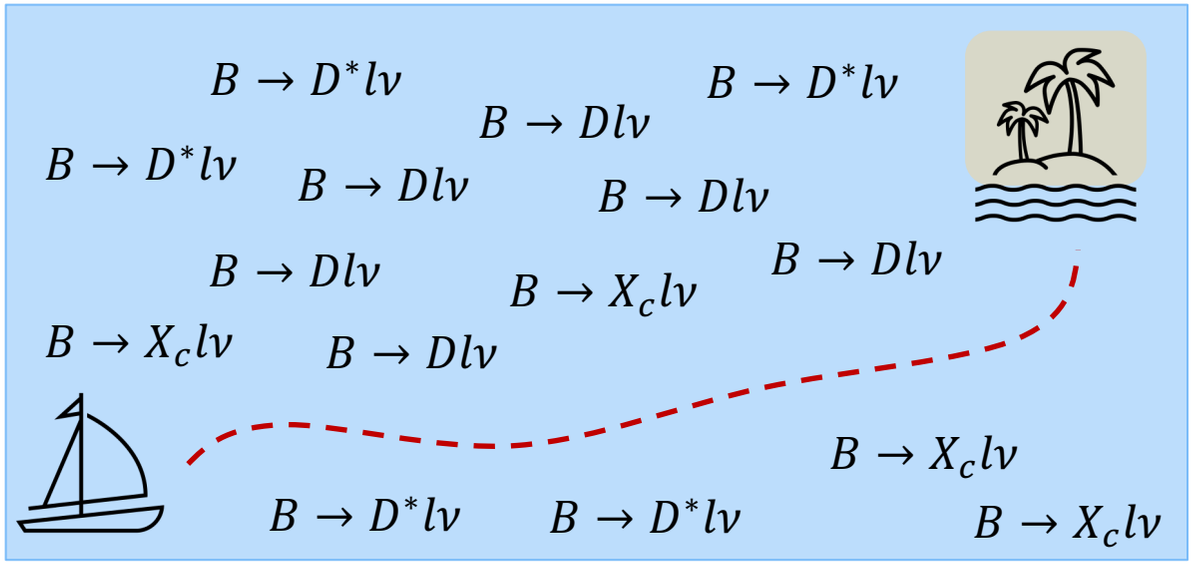

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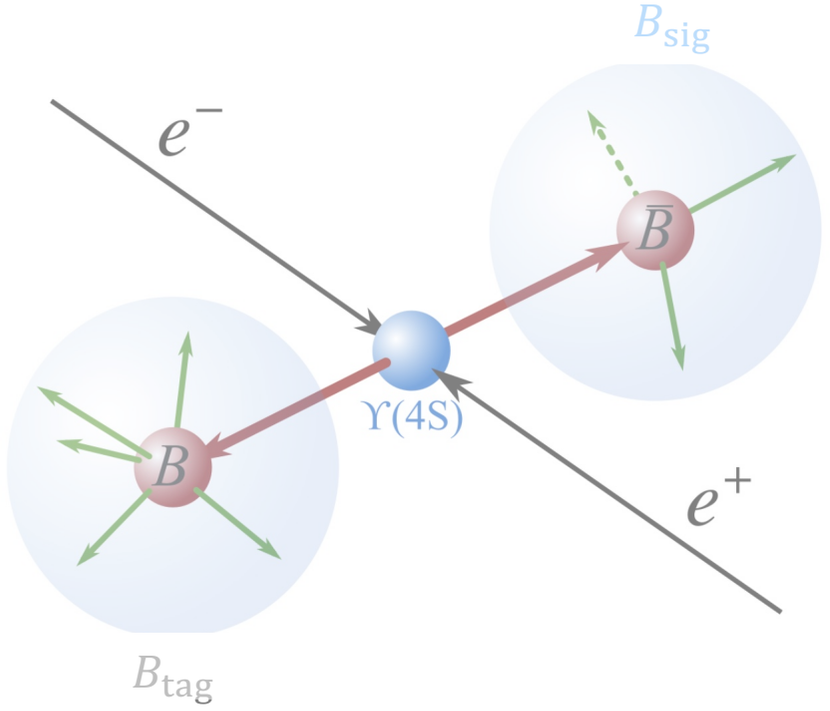

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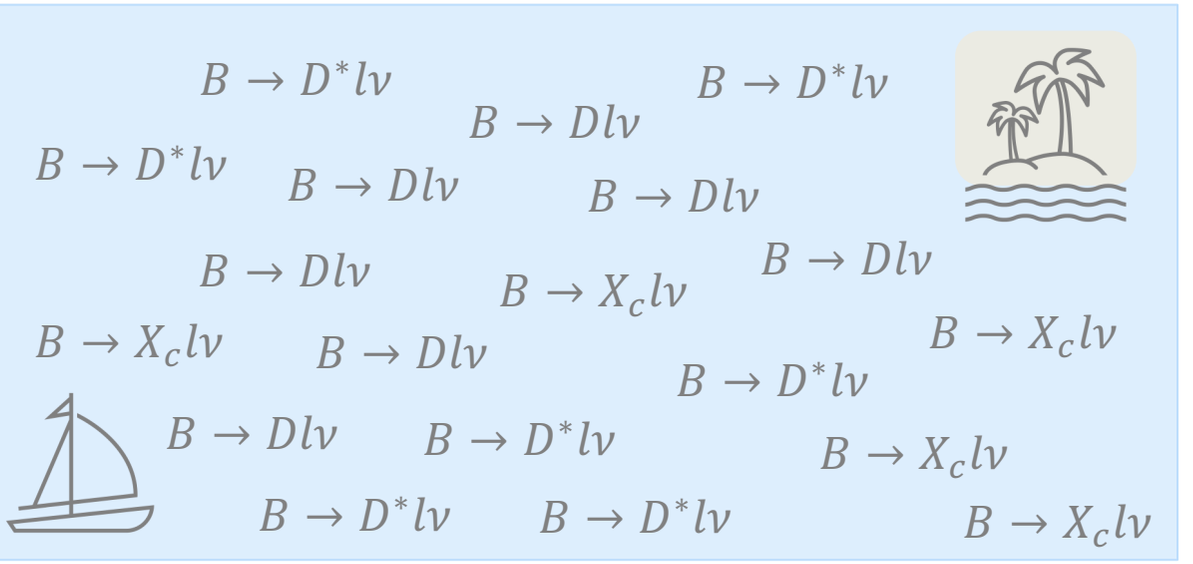


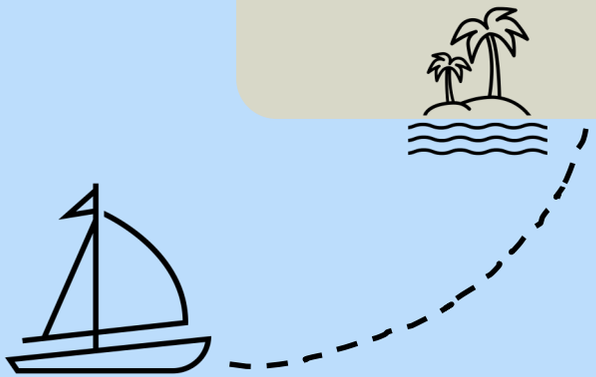
Approaches are theoretically and experimentally independent

SM PRECISION MEASUREMENTS

$$\underbrace{\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}}_{\text{CKM Matrix}}$$

Form-factor measurements

SM precision measurements



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Form-factor measurements

SM precision measurements

Untagged $B \to D^* l\nu$ at Belle II

Tagged $B \to D^* l\nu$ at Belle

Other $|V_{cb}|$ at Belle II

$|V_{cb}|$

SM PRECISION MEASUREMENTS

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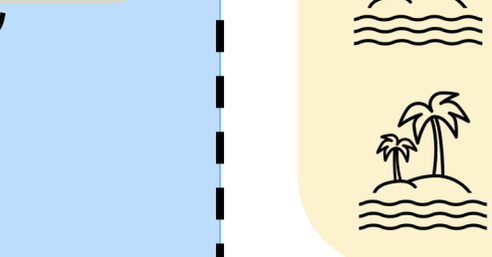


Untagged $B \to D^* l\nu$ at Belle II

Tagged $B \to D^* l\nu$ at Belle

Other $|V_{cb}|$ at Belle II

$|V_{cb}|$

Untagged $B \to \pi l\nu$ at Belle II

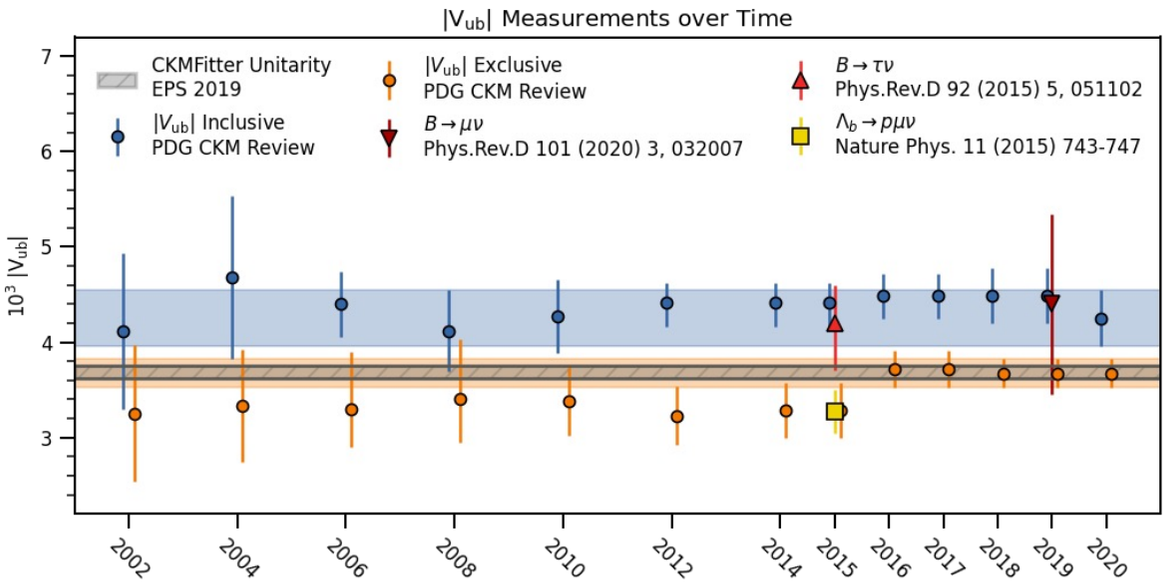
Other $|V_{ub}|$ at Belle II

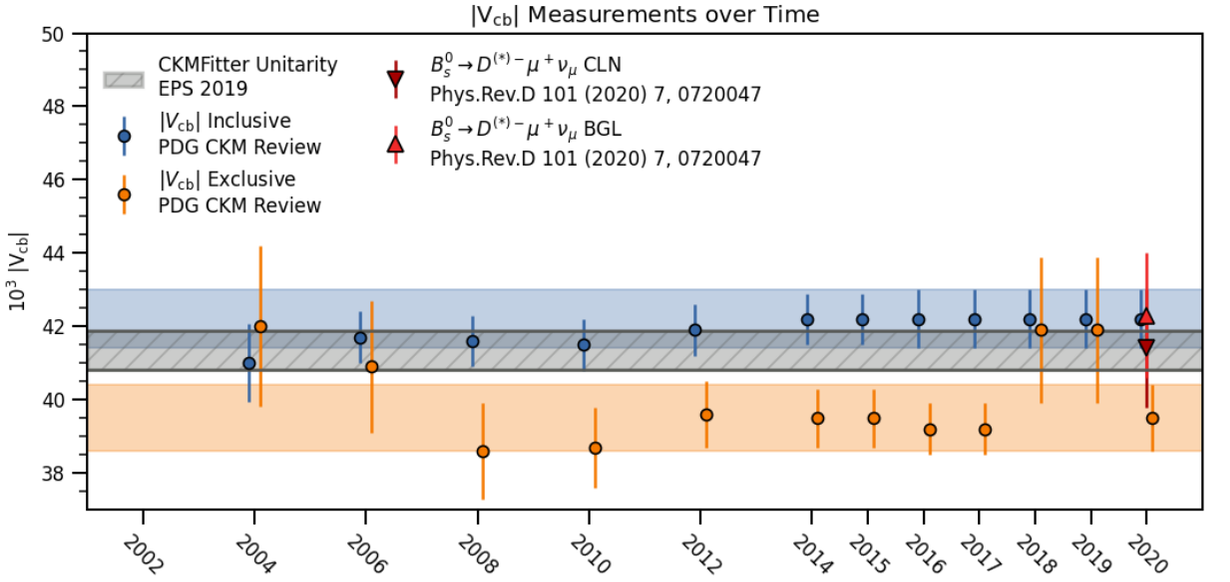
Tagged simultaneous exclusive and inclusive measurement of $|V_{ub}|$ at Belle

$|V_{ub}|$

MOTIVATION: CKM MATRIX ELEMENTS

- Test SM by over-constraining unitarity triangle using CKM matrix elements
- Important inputs to SM rates of ultra rare decays
- Tension between exclusive and inclusive $|V_{xb}|$ measurements at level of 2-3σ





$|V_{XB}|$ FROM SEMILEPTONIC DECAYS

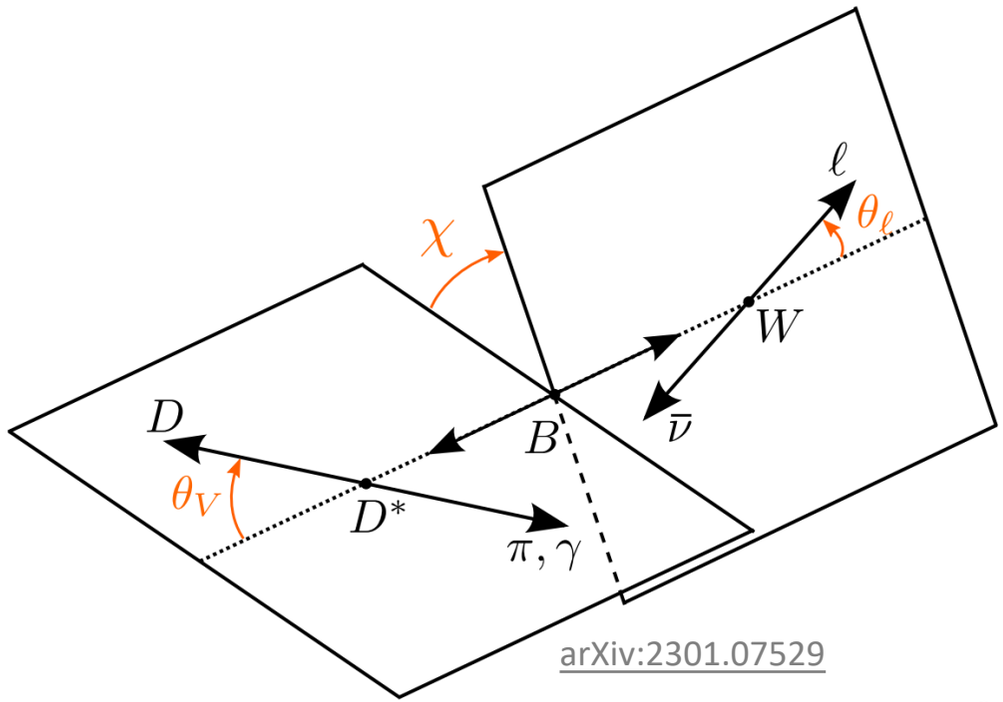
- Semileptonic: leptonic and hadronic currents factorize
- Describe kinematics using

Hadronic recoil:
$w = \frac{p_B \cdot p_X}{m_B m_X}$

or

Momentum transfer squared:
$q^2 = (p_B - p_X)^2$

and the angles θ_l, θ_v, χ



arXiv:2301.07529

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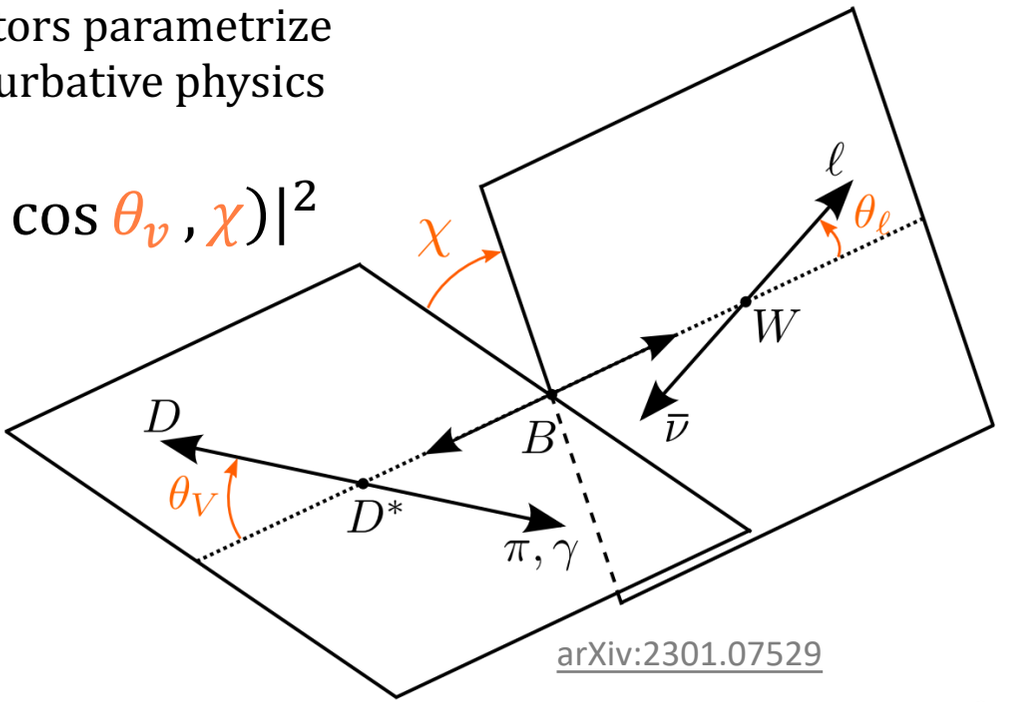
  and the angles θ_l, θ_v, χ
- Exclusive:

Form factors parametrize non-perturbative physics

$$\frac{d\mathcal{B}}{dq^2/w\, d\cos\theta_l\, d\cos\theta_v\, d\chi} \propto |V_{xb}|^2 \times |FF(q^2/w, \cos\theta_l, \cos\theta_v, \chi)|^2$$



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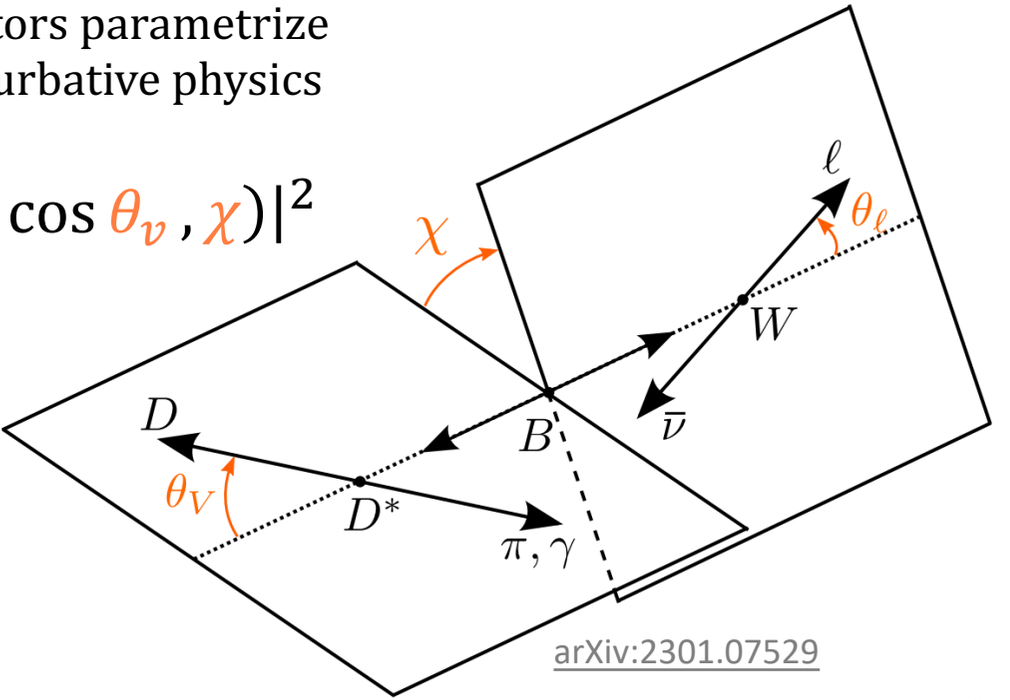
- Inclusive:

Operator product expansion

$$\mathcal{B} \propto |V_{xb}|^2 \times \left[\Gamma(b \to q l \bar{\nu}_l) + \frac{1}{m_b} + \alpha_s + \cdots\right]$$



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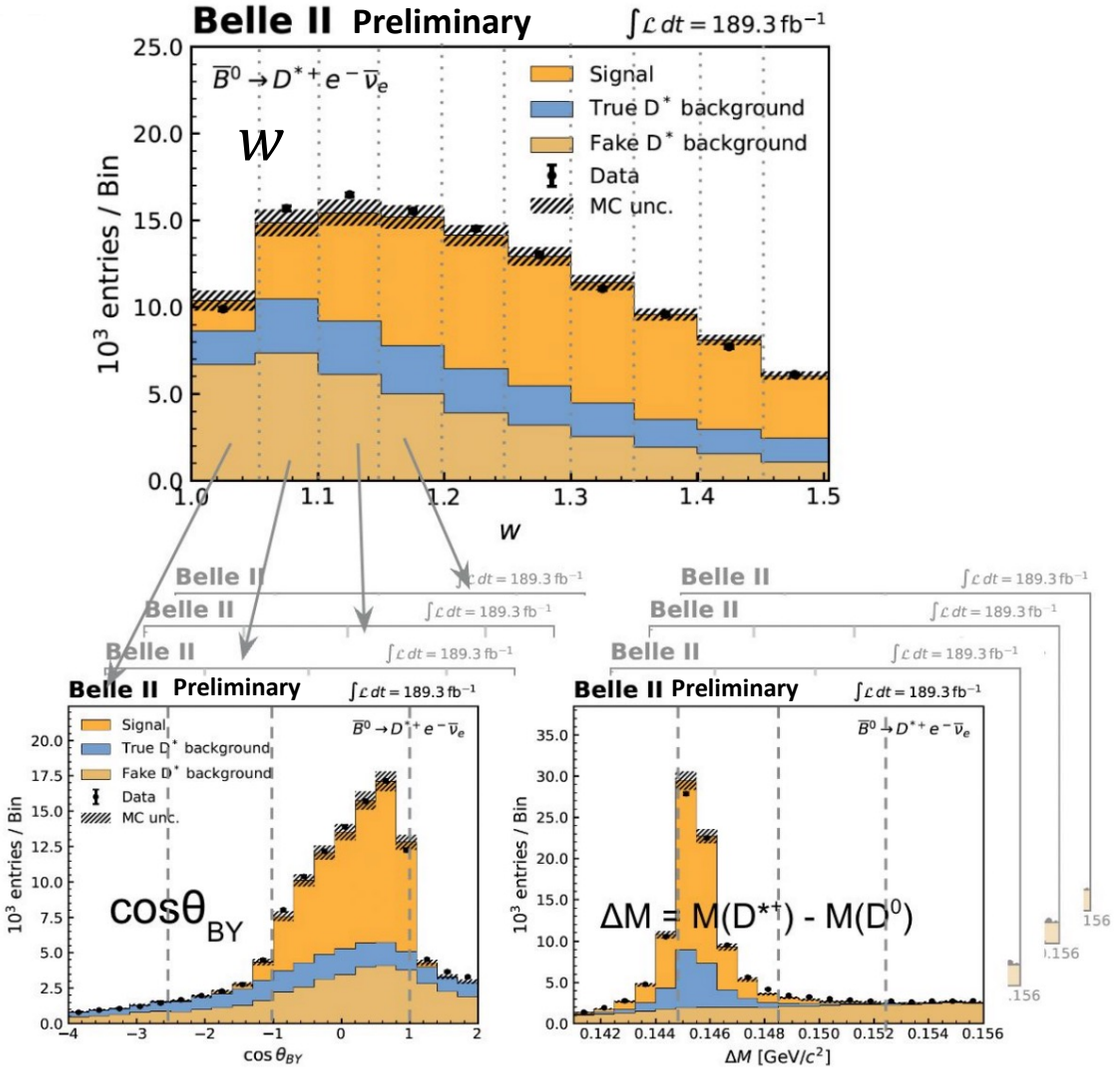
UNTAGGED $B \to D^* l\nu$ AT BELLE II

- Untagged reconstruction of $B^0 \to D^{*+} l^- \bar{\nu}_l$
  - $D^{*+} \to D^0 \pi^+$ and $D^0 \to K^- \pi^+$
- Extract signal yields independently in 8(10) bins of $\cos\theta_l$, $\cos\theta_v$, χ and w
- Perform 2D fits of $\cos\theta_{BY}$ ($Y = D^* l$) and ΔM

$$\cos\theta_{BY} = \frac{2E_B E_Y - m_B^2 - m_Y^2}{2p_B p_Y} \qquad \Delta M = M(D^*) - M(D^0)$$



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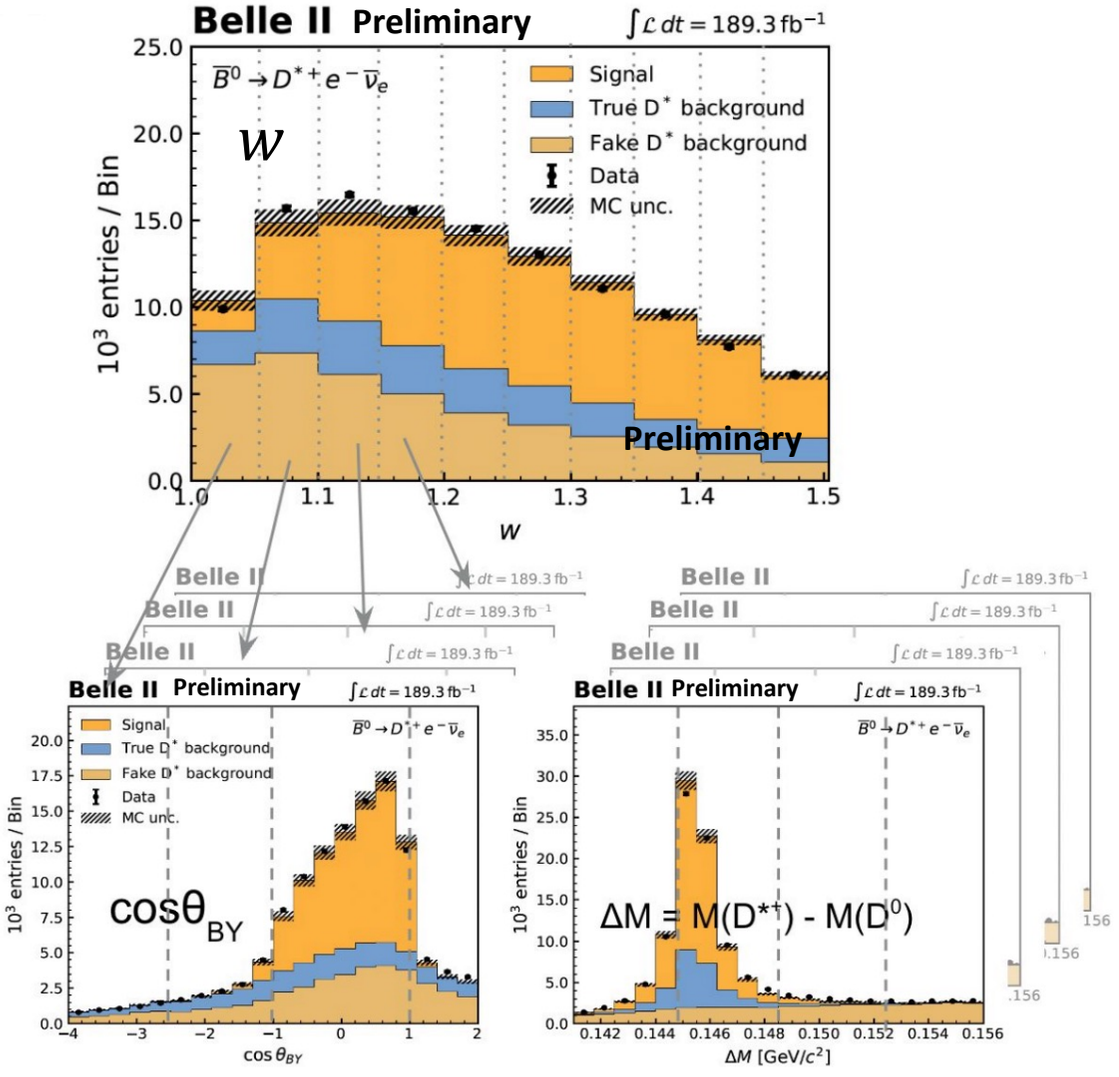
UNTAGGED $B \to D^* l\nu$ AT BELLE II

- Untagged reconstruction of $B^0 \to D^{*+} l^- \bar{\nu}_l$
  - $D^{*+} \to D^0 \pi^+$ and $D^0 \to K^- \pi^+$
- Extract signal yields independently in 8(10) bins of $\cos\theta_l$, $\cos\theta_\nu$, χ and w
- Perform 2D fits of $\cos\theta_{BY}$ ($Y = D^* l$) and ΔM

$$\cos\theta_{BY} = \frac{2E_B E_Y - m_B^2 - m_Y^2}{2p_B p_Y} \qquad \Delta M = M(D^*) - M(D^0)$$

- Unfolded yields obtained using singular value decomposition arXiv:hep-ph/9509307
- Converted to partial branching fractions $\Delta\Gamma_i$ using reconstruction efficiencies



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UNTAGGED $B \to D^* l\nu$ AT BELLE II

- Determine $|V_{cb}|$ by minimising χ^2:

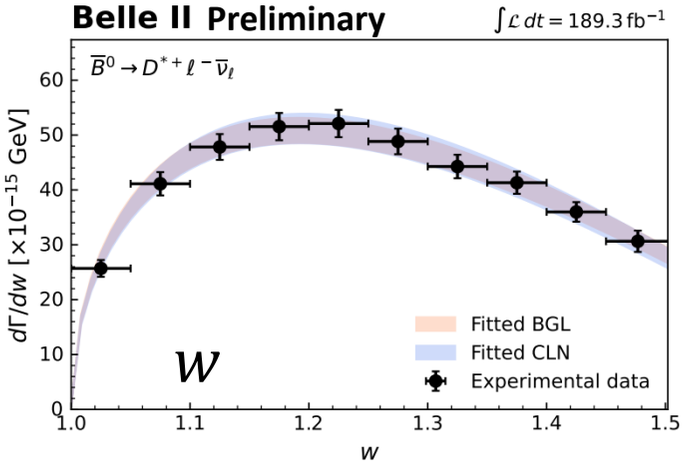
$$\chi^2 = \sum_{i,j}^{34} \left(\frac{\Delta\Gamma_i^{\text{obs}}}{\Gamma^{\text{obs}}} - \frac{\Delta\Gamma_i^{\text{pre}}}{\Gamma^{\text{pre}}} \right) C_{ij}^{-1} \left(\frac{\Delta\Gamma_j^{\text{obs}}}{\Gamma^{\text{obs}}} - \frac{\Delta\Gamma_j^{\text{pre}}}{\Gamma^{\text{pre}}} \right) + \frac{(\Gamma^{\text{obs}}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

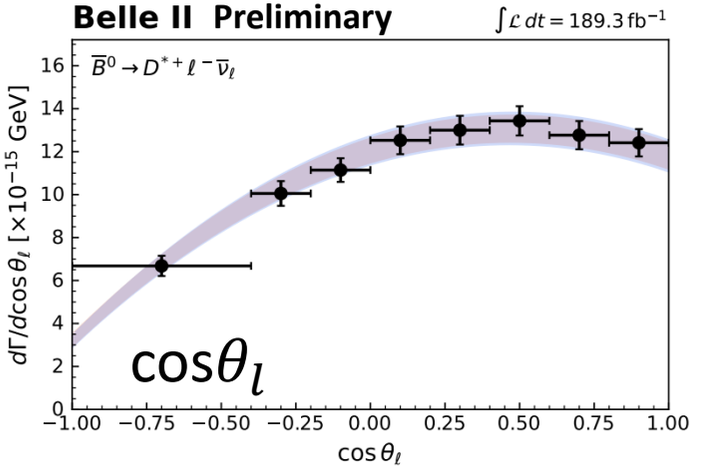
- Experimental observation
- Experimental covariance
- Theoretical prediction

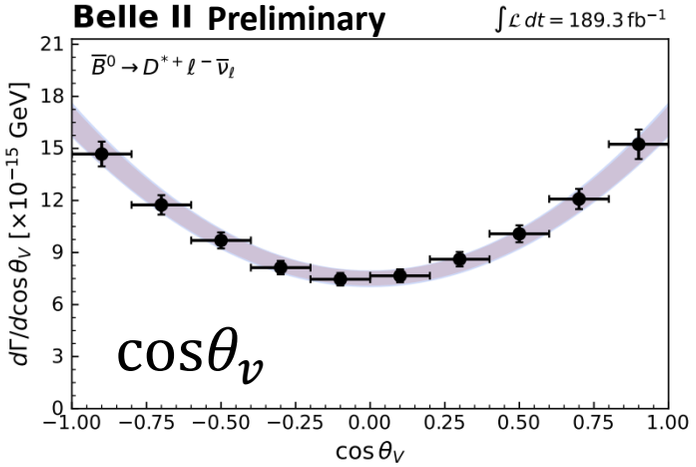
- Form-factor parameterizations:

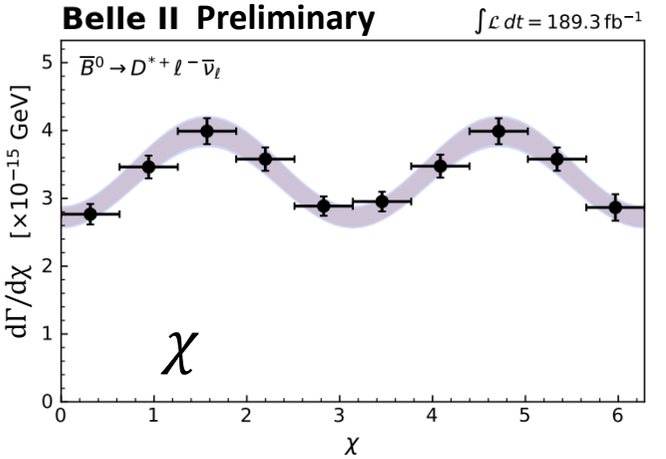
Caprini-Lellouch-Neubert (CLN) parameterization
Phys. Rev. D 56 (1997) 6895

Boyd-Grinstein-Lebed (BGL) parameterization
Nucl. Phys. B 530 (1998) 153









UNIVERSITÄT BONN

UNTAGGED $B \to D^* l\nu$ AT BELLE II

- Determine $|V_{cb}|$ by minimising χ^2:

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

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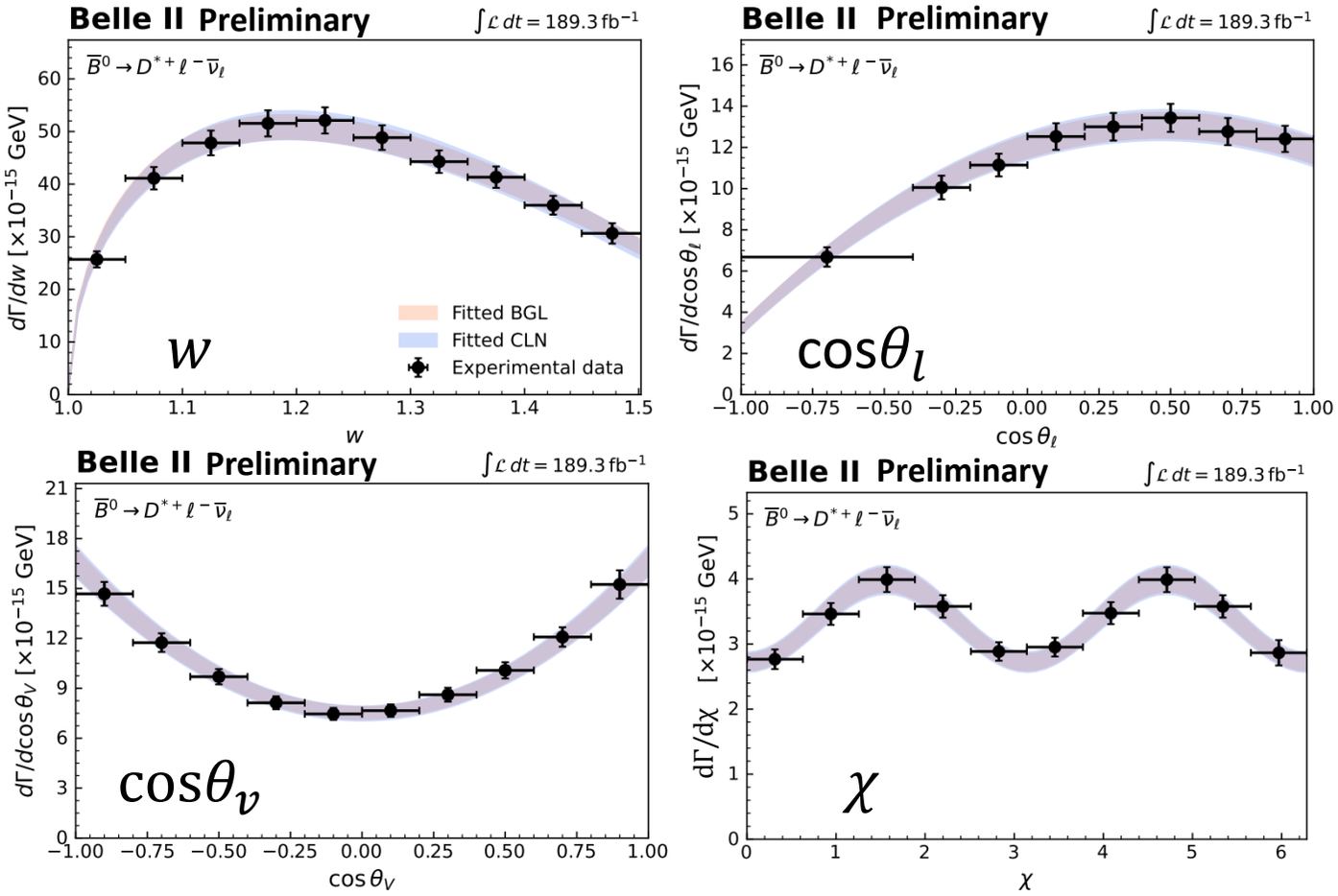


$$|V_{cb}|_{BGL} = (40.9 \pm 0.3_{stat} \pm 1.0_{syst} \pm 0.6_{theo}) \times 10^{-3}$$
$$|V_{cb}|_{CLN} = (40.4 \pm 0.3_{stat} \pm 1.0_{syst} \pm 0.6_{theo}) \times 10^{-3}$$

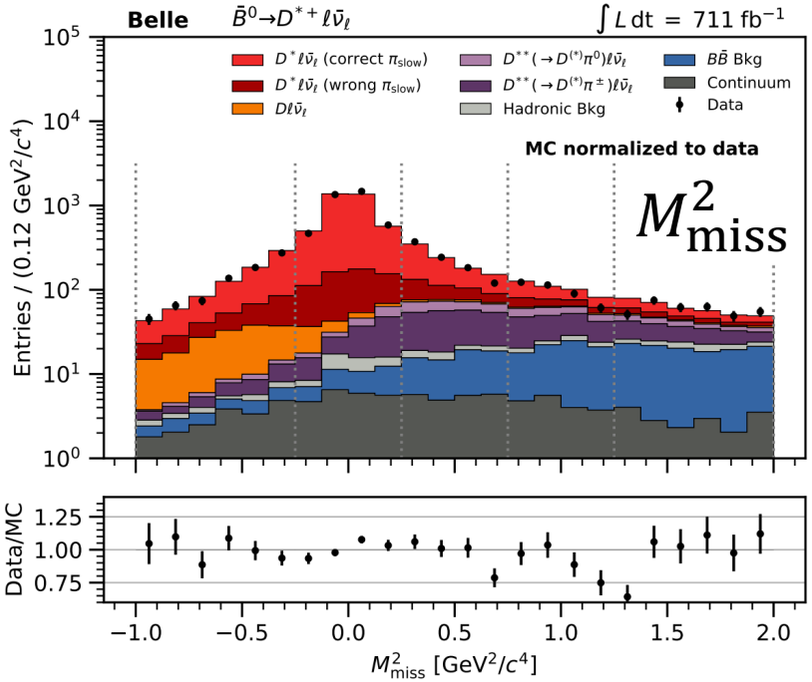
Phys. Rev. D 89 (2014) 114504

- LQCD at zero recoil (w = 1) used for normalization
- Shifts exclusive average closer to inclusive average

Accepted by PRD, arXiv:2301.07529

TAGGED $B \to D^* l\nu$ AT BELLE

- Use Full Event Interpretation to reconstruct B_{tag} Comput Softw Big Sci 3, 6 (2019)
- Reconstruct $B \to D^* l\bar{\nu}_l$ with $D^{*+} \to D^{0/+}\pi^{+/0}$ and $D^{*0} \to D^0\pi^0$ ⟶ Reconstruct D in 16 modes
- Missing mass squared: $M^2_{\text{miss}} = (p_{e^+e^-} - p_{B_{\text{tag}}} - p_{D^*} - p_l)^2 \approx 0$ for signal



UNIVERSITÄT BONN

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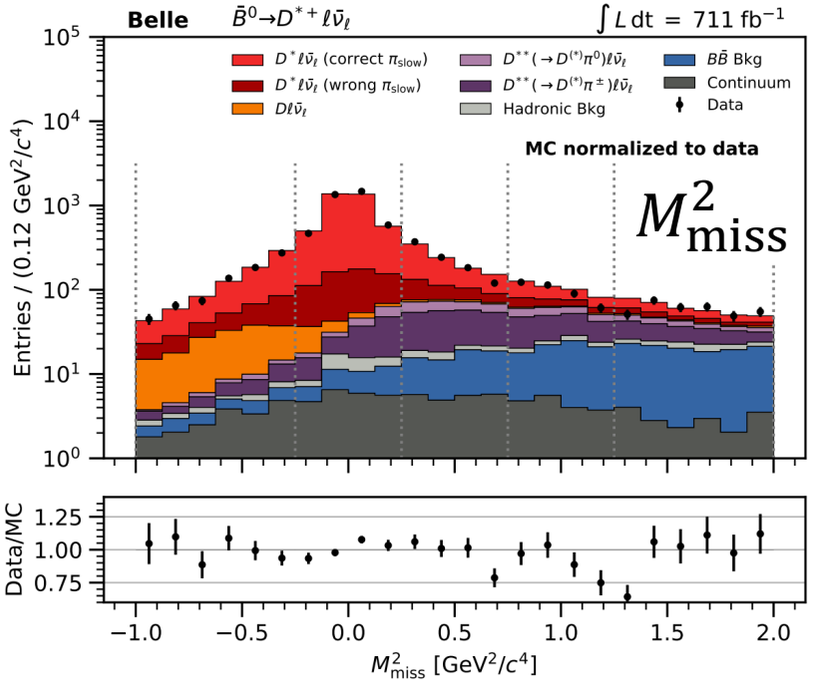
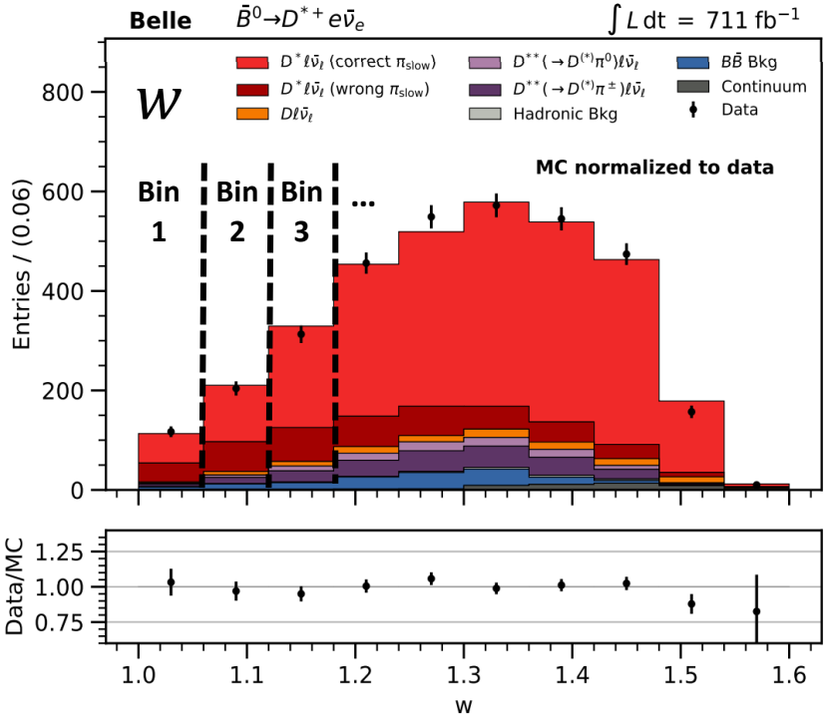
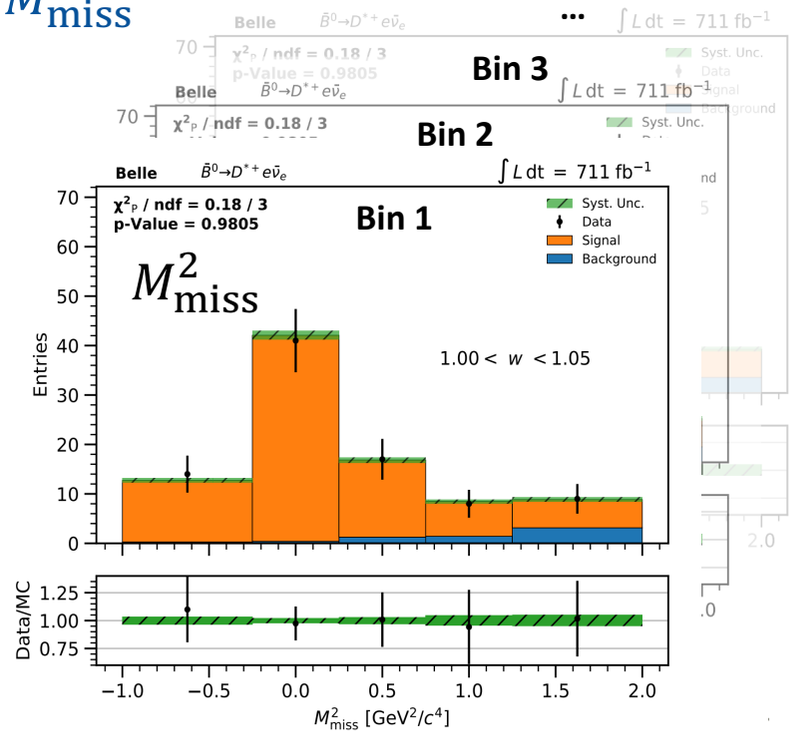
- Missing mass squared: $M^2_{\text{miss}} = p_{e^+e^-} - p_{B_{\text{tag}}} - p_\pi - p_e \approx 0$ for signal
- Extract yields independently in 10 bins of $\cos\theta_l$, $\cos\theta_v$, χ and w by fitting M^2_{miss}

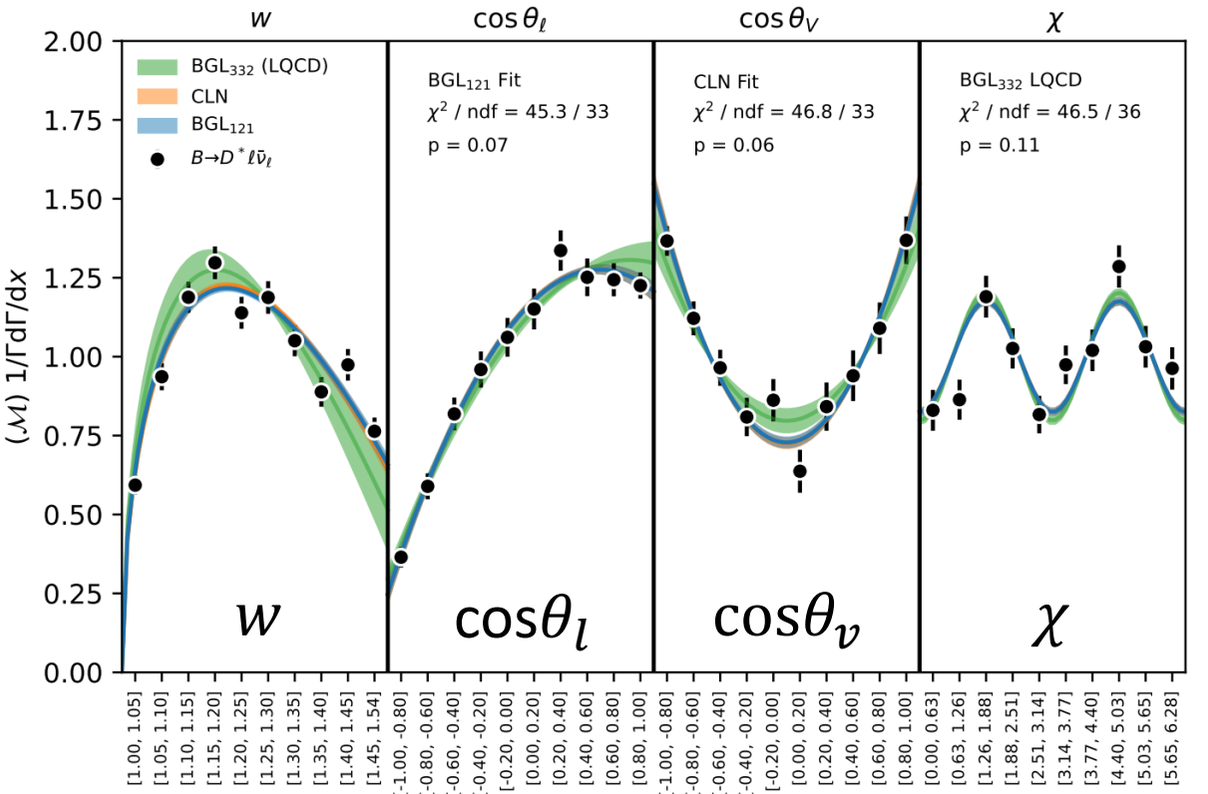






TAGGED $B \to D^* l\nu$ AT BELLE

- Similar procedure to untagged analysis:
  - Unfold yields using matrix inversion
  - Calculate partial branching fractions
  - Determine $|V_{cb}|$ by χ^2 minimisation
- Provide full experimental covariance matrix



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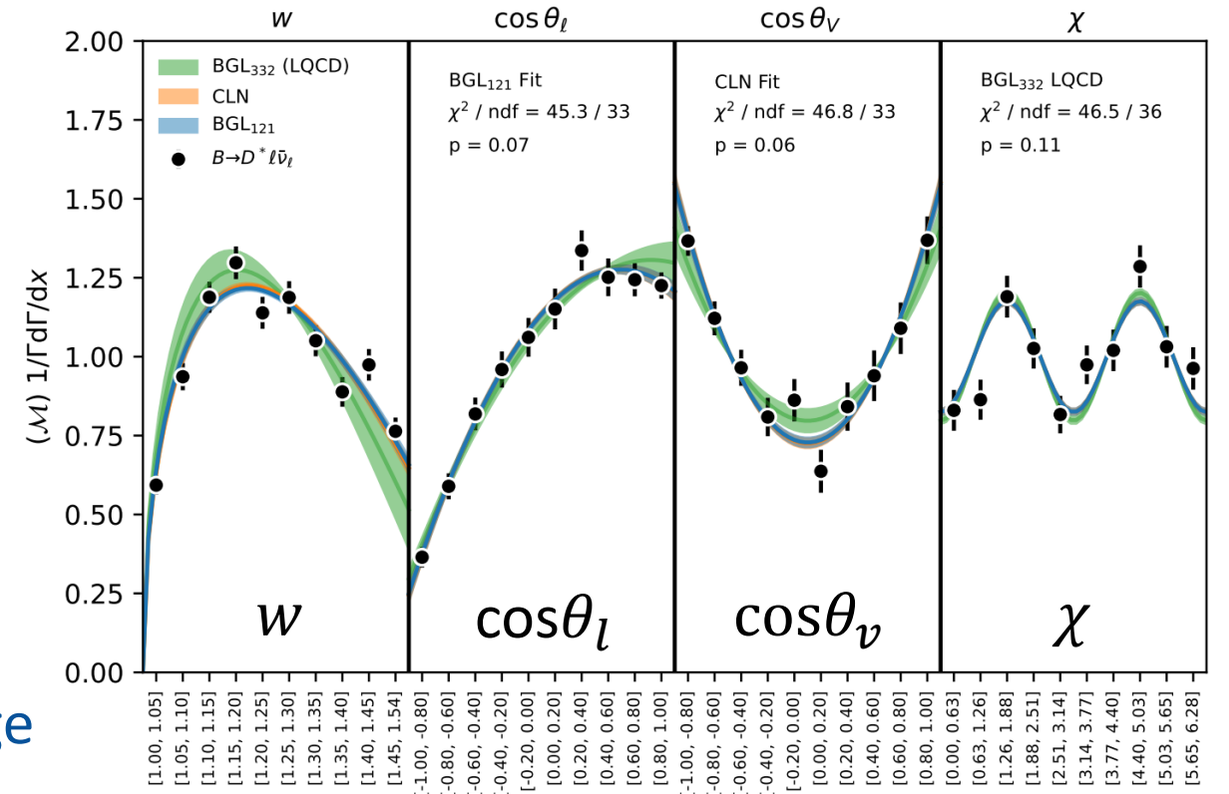
  - Unfold yields using matrix inversion
  - Calculate partial branching fractions
  - Determine $|V_{cb}|$ by χ^2 minimisation
- Provide full experimental covariance matrix

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

- Also shifts exclusive closer to inclusive average



- In addition, include lattice QCD results beyond non-zero recoil Eur. Phys. J. C 82 (2022) 1141
- Including full lattice information results in poor fits and lower $|V_{cb}|$ values

Accepted by PRD, arXiv:2301.07529

TAGGED $B \to D^* l\nu$ AT BELLE

- Also measure forward-backward asymmetry A_{FB}:

$$A_{FB} = \left[\int_0^1 - \int_{-1}^0\right] d\cos\theta_l \frac{d\Gamma}{d\cos\theta_l}$$

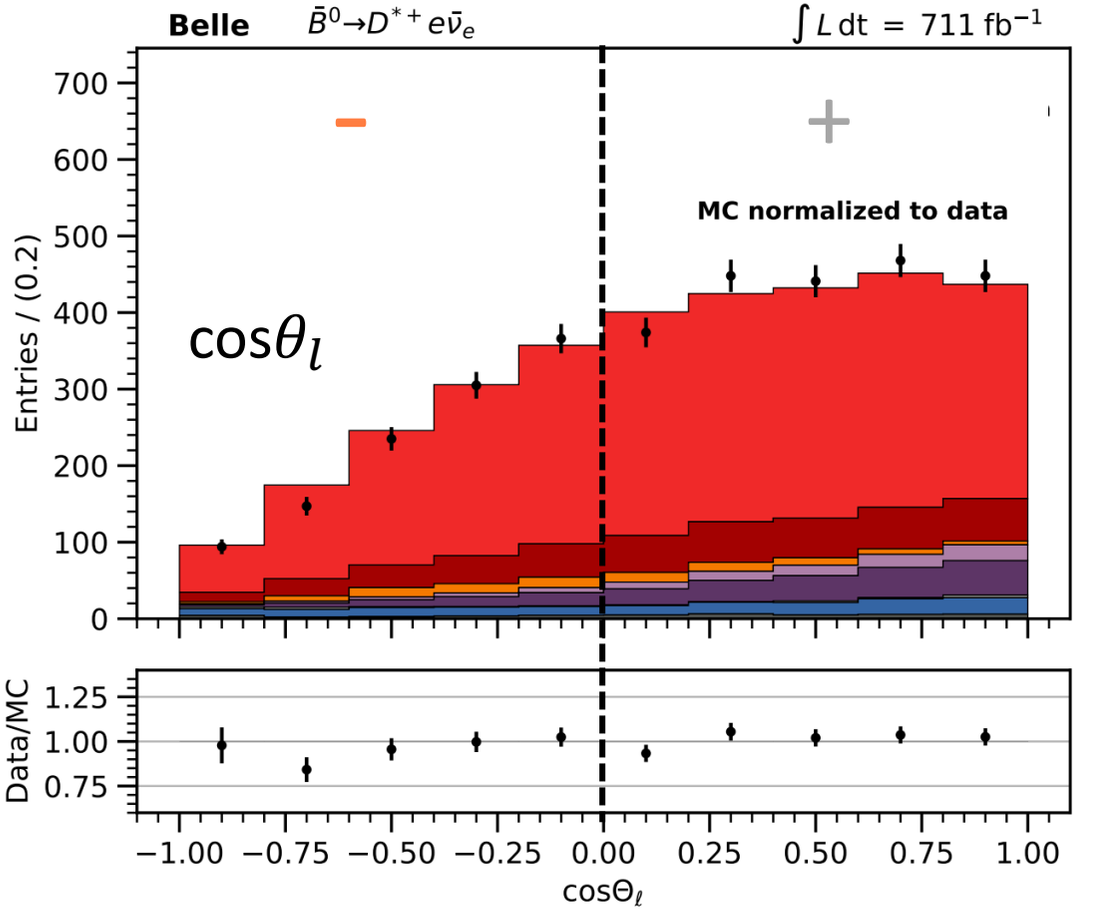
(+ for $\int_0^1$, − for $\int_{-1}^0$)

- Test lepton universality by evaluating

$$\Delta A_{\mathrm{FB}} = A_{\mathrm{FB}}^{e} - A_{\mathrm{FB}}^{\mu} \quad \text{and} \quad R_{e\mu} = \frac{\mathcal{B}(B \to D^* e\nu)}{\mathcal{B}(\mathrm{B} \to D^* \mu\nu)}$$

$$\Delta A_{\mathrm{FB}} = 0.022 \pm 0.026_{\mathrm{stat}} \pm 0.007_{\mathrm{syst}}$$
$$R_{e\mu} = 0.990 \pm 0.021_{\mathrm{stat}} \pm 0.023_{\mathrm{syst}}$$

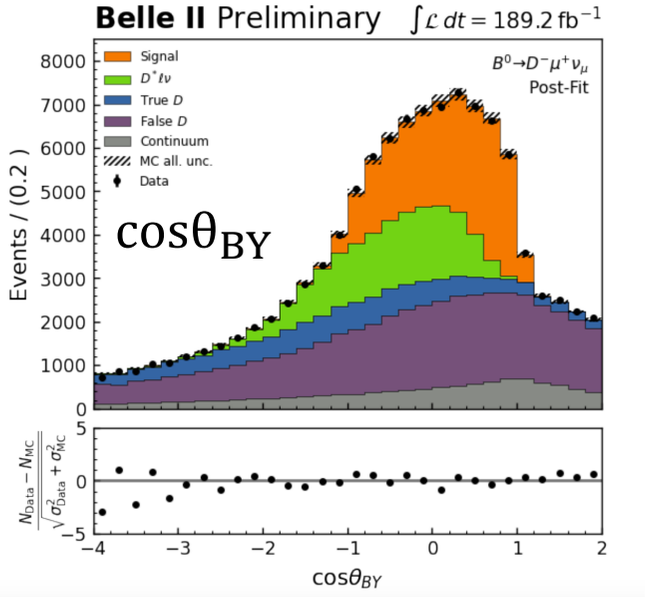
- Agrees with the SM expectation



OTHER $|V_{CB}|$ AT BELLE II

UNTAGGED $B \to Dl\nu$ arXiv:2210.13143

- Large backgrounds from B→ $D^* l\nu$
- Binned fit to $\cos\theta_{\mathrm{BY}}$ in ten w bins



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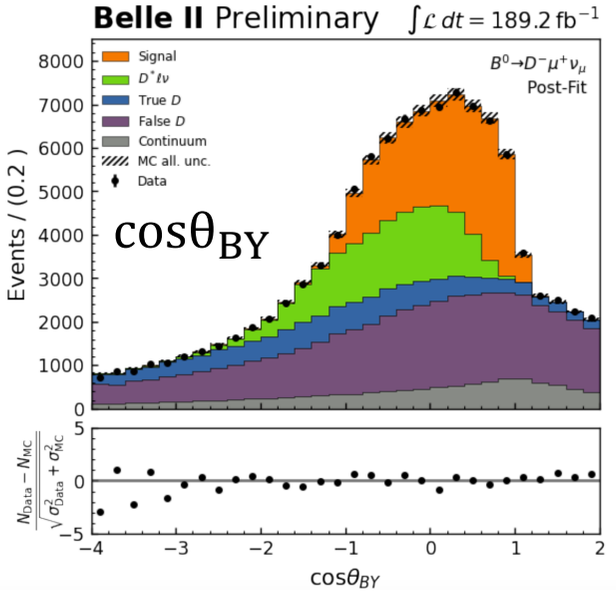
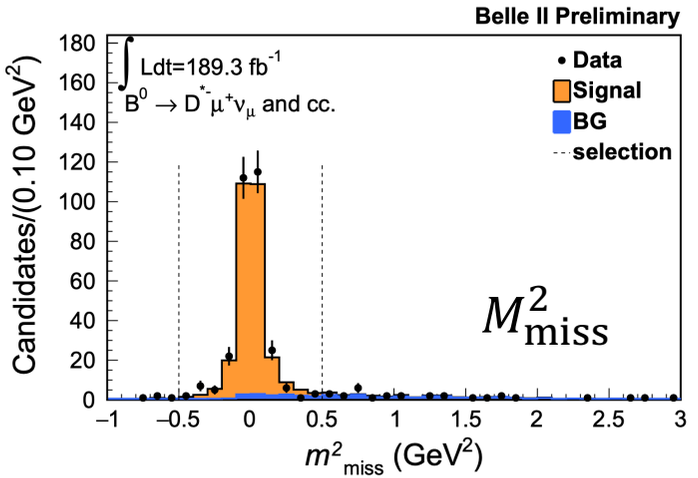


TAGGED $B^0 \to D^{*+} l\nu$ arXiv:2301.04716

- Fit to M^2_{miss} in ten w bins



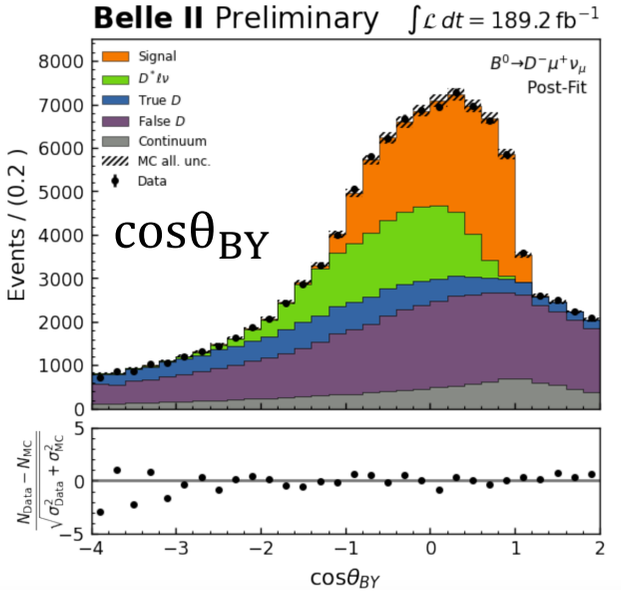
OTHER $|V_{CB}|$ AT BELLE II

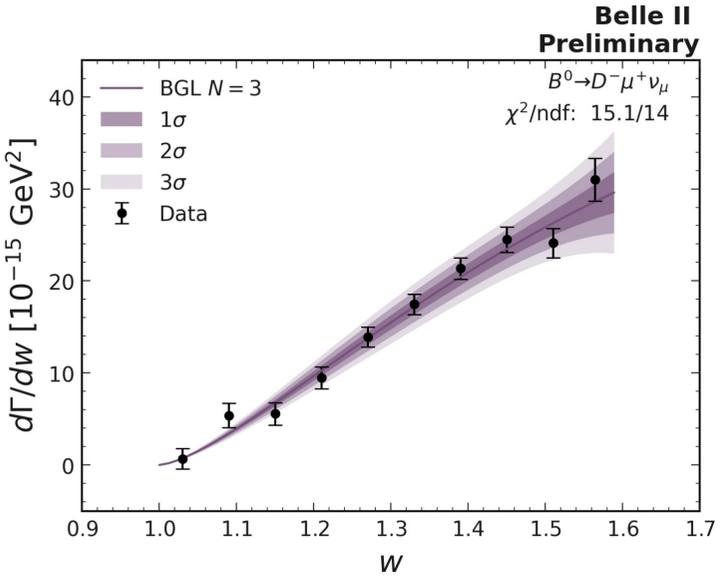
UNTAGGED $B \to Dl\nu$ arXiv:2210.13143

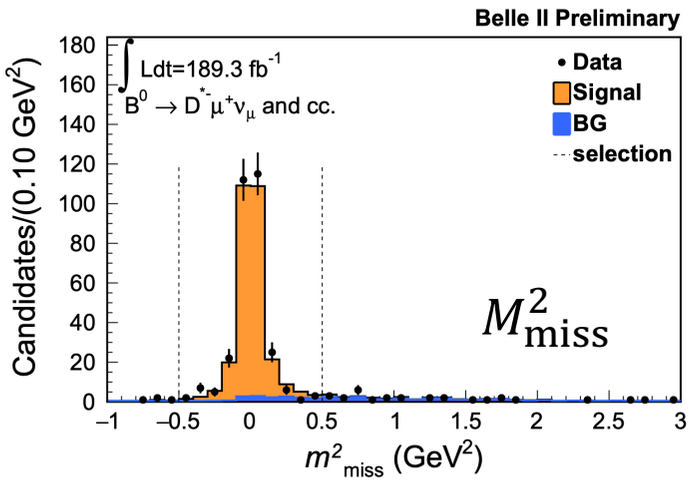
- Large backgrounds from B→ $D^* l\nu$
- Binned fit to $\cos\theta_{\mathrm{BY}}$ in ten w bins
- Combined fit to BGL expansion and form-factor LQCD constraints Phys. Rev. D 92, 034506 Phys. Rev. D 92, 054510

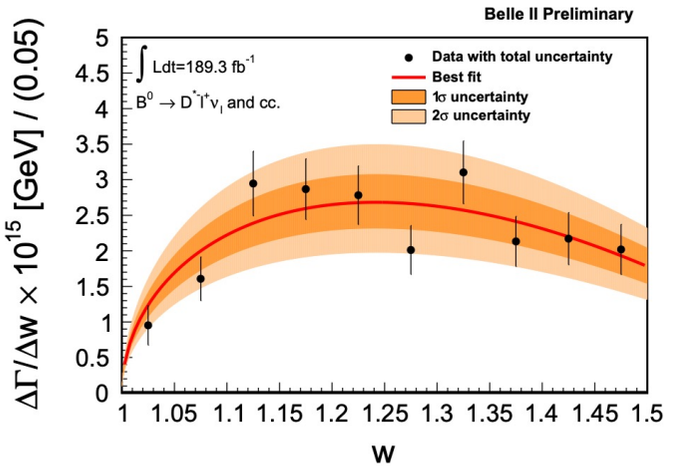
TAGGED $B^0 \to D^{*+} l\nu$ arXiv:2301.04716

- Fit to M^2_{miss} in ten w bins
- Fit CLN-parametrized form factor to differential decay rates









OTHER $|V_{CB}|$ AT BELLE II

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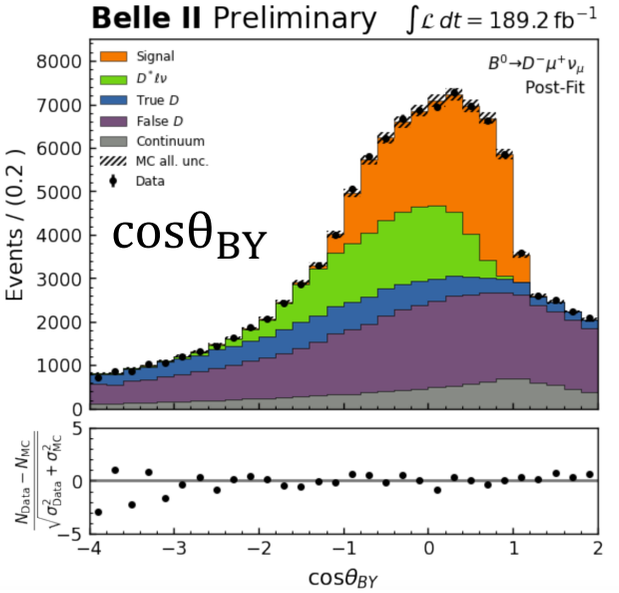

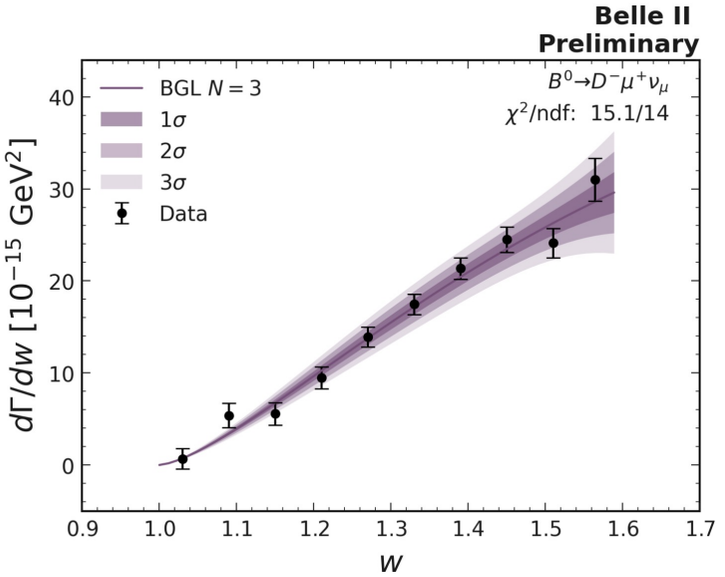

TAGGED $B^0 \to D^{*+} l\nu$ arXiv:2301.04716

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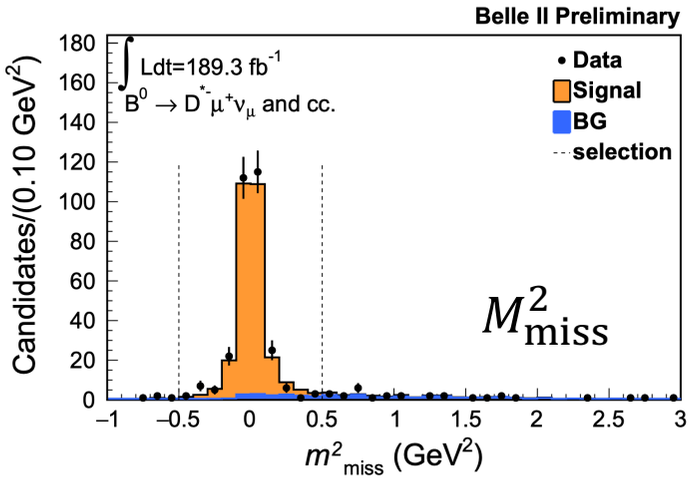
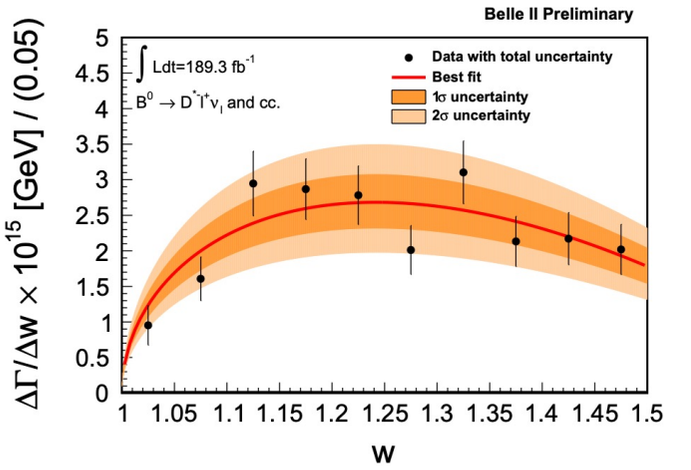




$$|V_{cb}| = (38.3 \pm 1.2_{\mathrm{tot}}) \times 10^{-3}$$

$$|V_{cb}| = (37.9 \pm 2.7_{\mathrm{tot}}) \times 10^{-3}$$

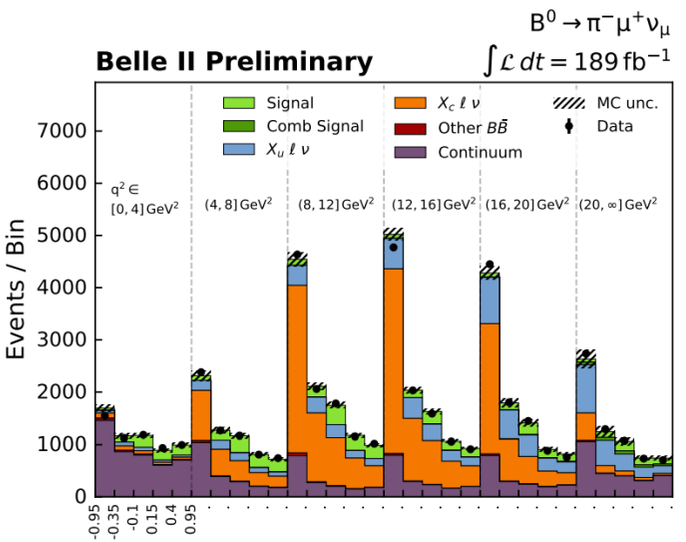
Consistent with exclusive world-average

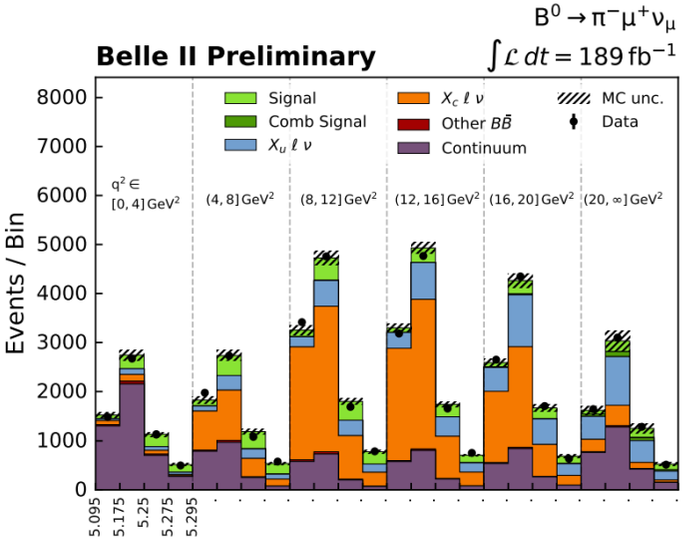
UNIVERSITÄT BONN

UNTAGGED $B \to \pi l \nu$ AT BELLE II

arXiv:2210.04224

- Suffers from large B→ $X_c l\nu$ and continuum backgrounds
  - Suppressed using BDTs
- Binned fit to ΔE and M_{bc} in six q^2 bins





$$\Delta E = E_B - E_{beam} \text{ (GeV)}$$

$$M_{bc} = \sqrt{E_{beam}^2 - |\overrightarrow{p_B}|^2} \text{ (GeV)}$$

UNIVERSITÄT BONN

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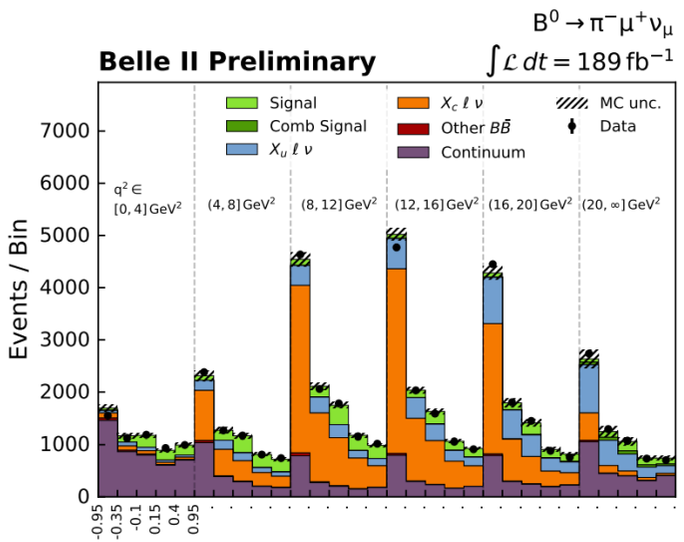

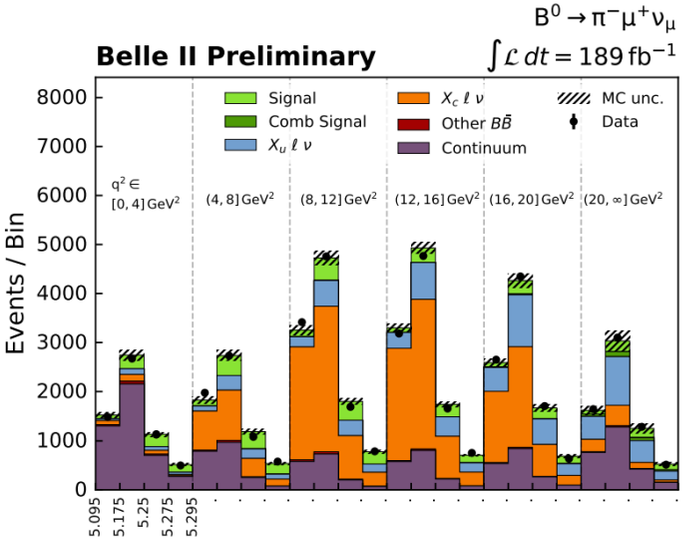

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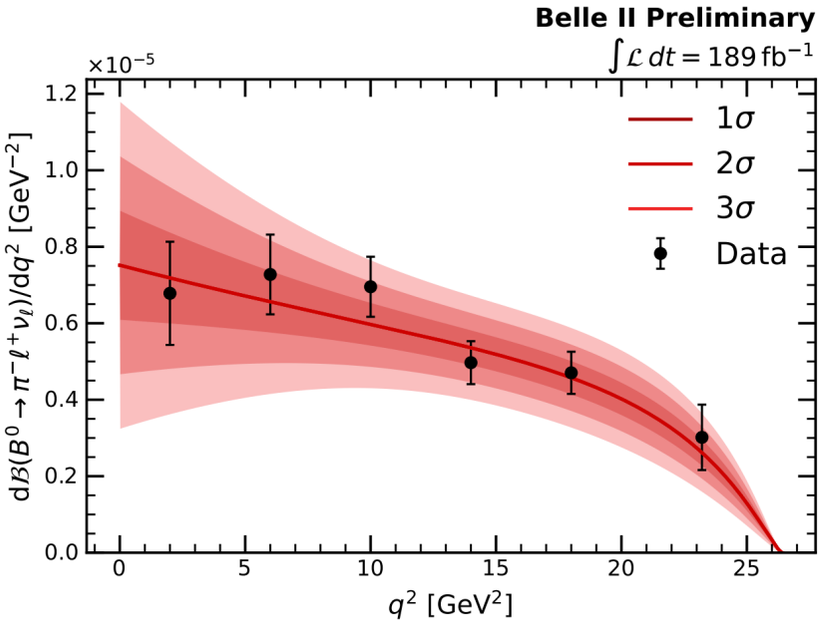


Phys. Rev. D 82, 099902

- Combined fit to Bourrely-Caprini-Lellouch (BCL) expansion and form-factor LQCD constraints Phys. Rev. D 92, 014024

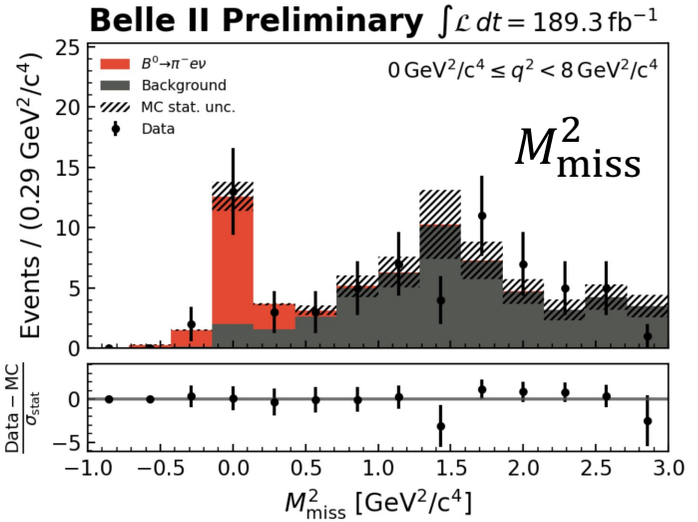
$$|V_{ub}| = (3.55 \pm 0.12_{stat} \pm 0.13_{syst} \pm 0.17_{theo}) \times 10^{-3}$$

- In agreement with exclusive world-average

OTHER $|V_{ub}|$ AT BELLE II

TAGGED $B \to \pi e \nu$ arXiv:2206.08102

- Fit to M^2_{miss} in three q^2 bins
- Combined fit to BCL expansion and form-factor LQCD constraints



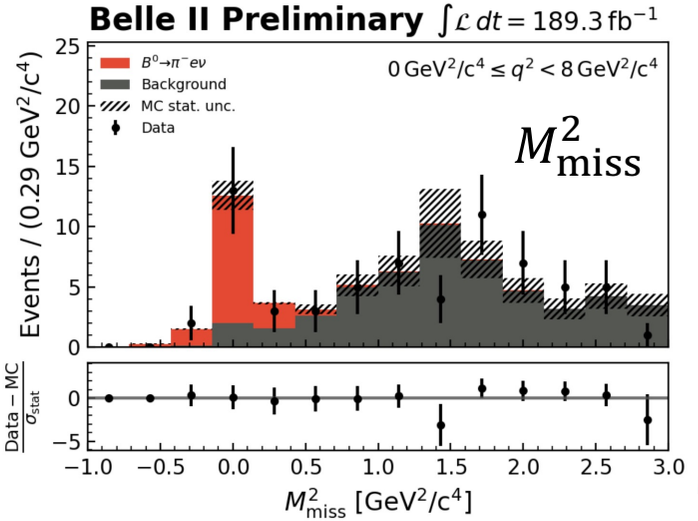
OTHER $|V_{ub}|$ AT BELLE II

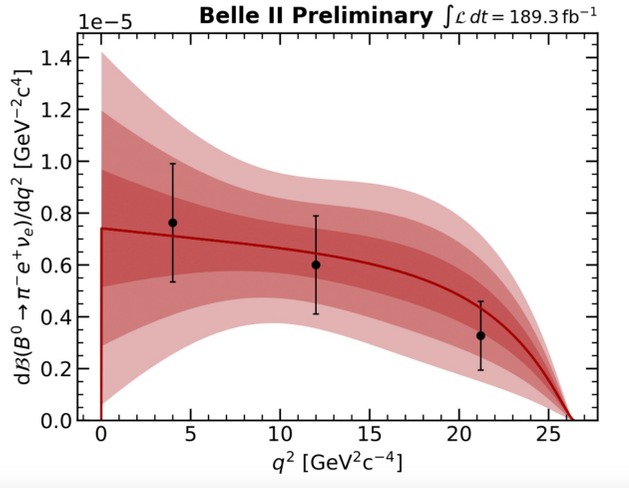
TAGGED $B \to \pi e \nu$ arXiv:2206.08102

- Fit to M^2_{miss} in three q^2 bins
- Combined fit to BCL expansion and form-factor LQCD constraints

$$|V_{ub}| = (3.88 \pm 0.45_{\mathrm{tot}}) \times 10^{-3}$$

- In agreement with exclusive average





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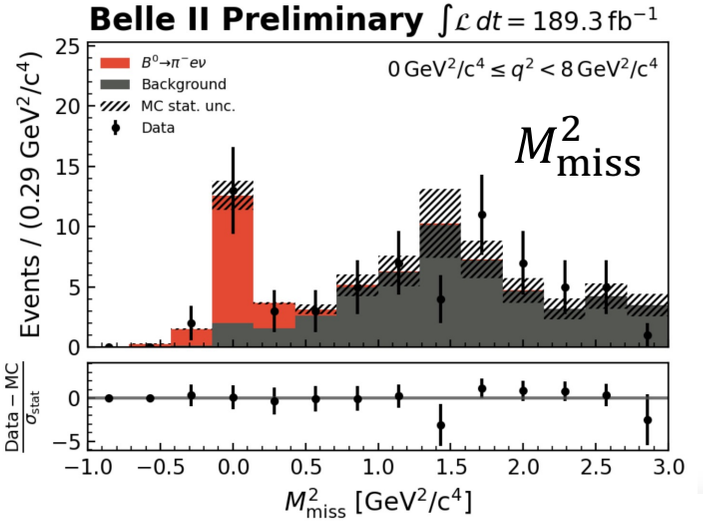
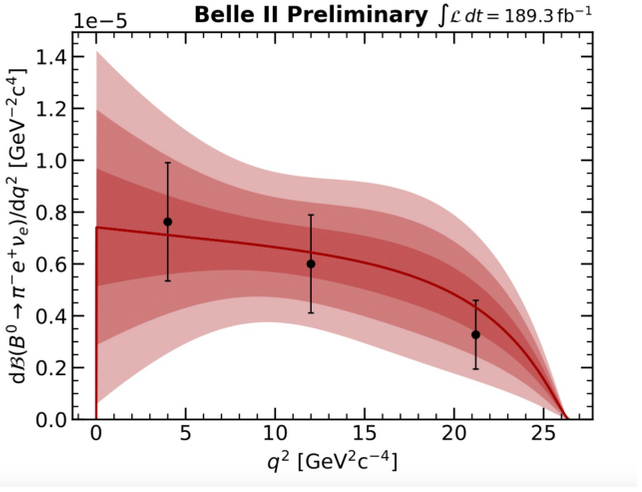
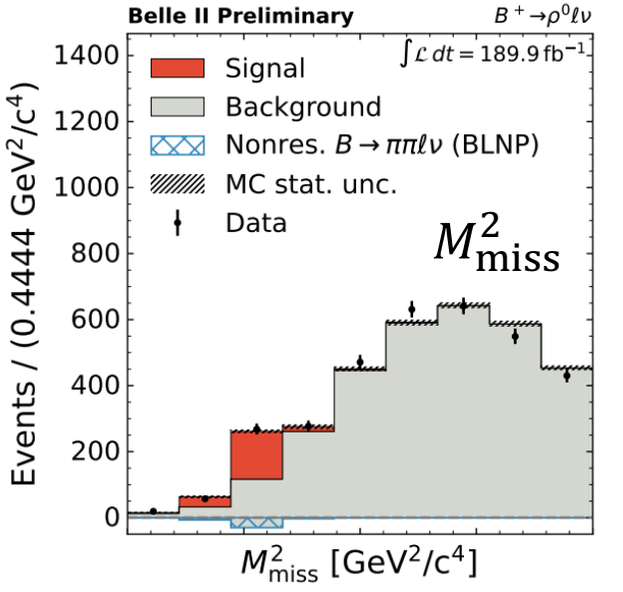
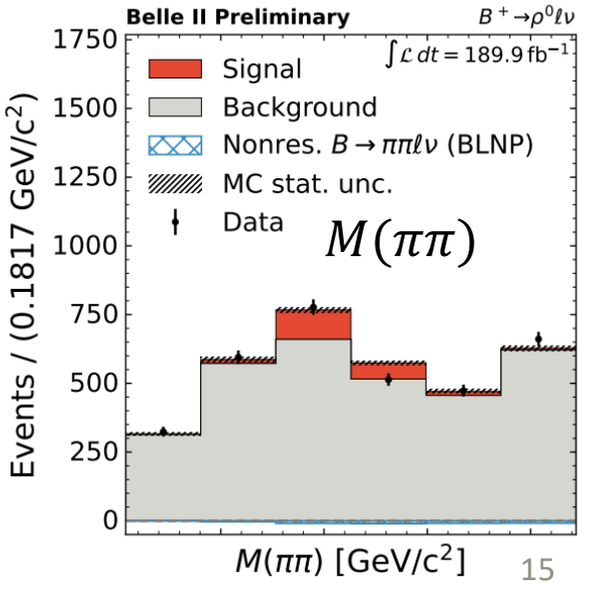




TAGGED $B \to \rho l \nu$ arXiv:2211.15270

- Fit to M^2_{miss} and di-pion mass: $M(\pi\pi)$
- Negative nonresonant $B \to \pi\pi l \nu$ yield





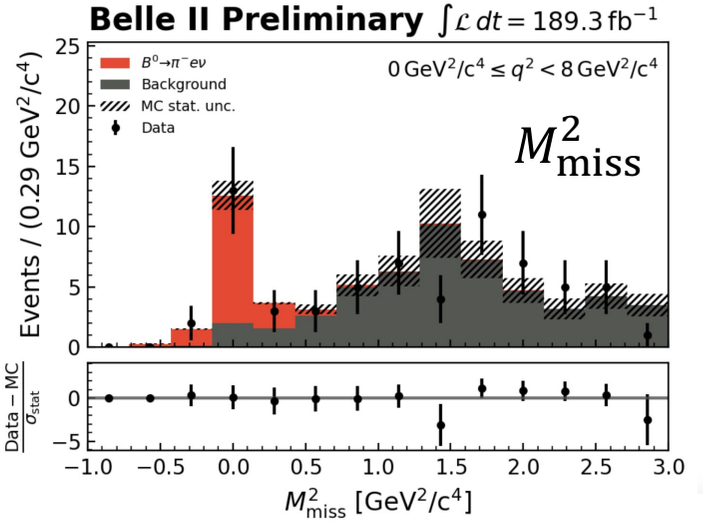
OTHER $|V_{ub}|$ AT BELLE II

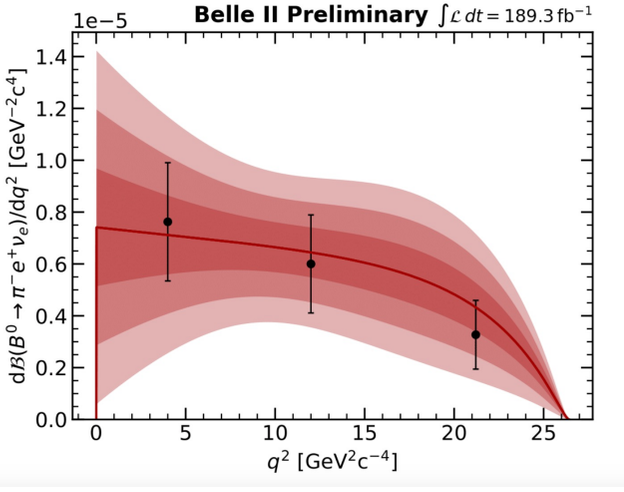
TAGGED $B \to \pi e \nu$ arXiv:2206.08102

- Fit to M^2_{miss} in three q^2 bins
- Combined fit to BCL expansion and form-factor LQCD constraints

$$|V_{ub}| = (3.88 \pm 0.45_{\mathrm{tot}}) \times 10^{-3}$$

- In agreement with exclusive average



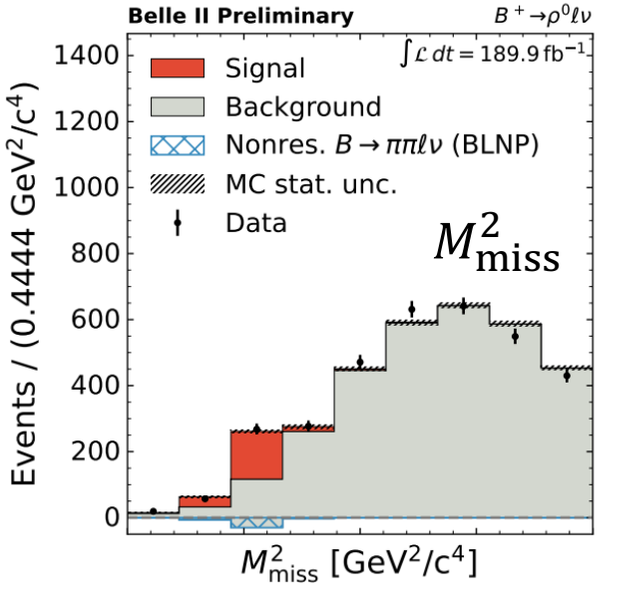


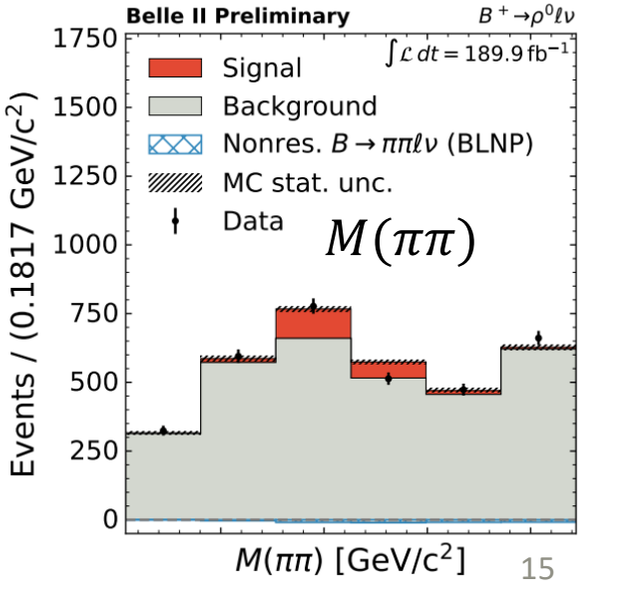
TAGGED $B \to \rho l \nu$ arXiv:2211.15270

- Fit to M^2_{miss} and di-pion mass: $M(\pi\pi)$
- Negative nonresonant $B \to \pi\pi l \nu$ yield

$$\mathcal{B}(B^+ \to \rho^0 l \nu) = (1.77 \pm 0.23_{\mathrm{stat}} \pm 0.36_{\mathrm{syst}}) \times 10^{-4}$$

- Agrees with world-average

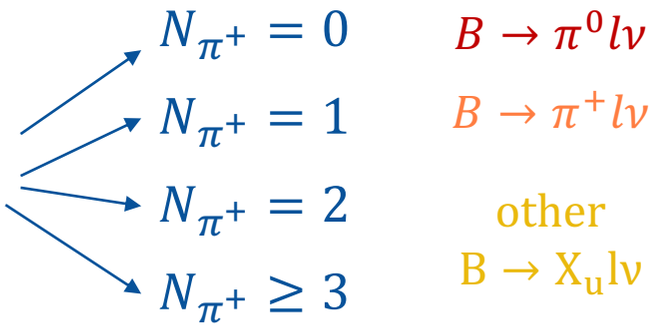




Submitted to PRL, arXiv:2303.17309

TAGGED SIMULTANEOUS EXCL. AND INCL. $|V_{ub}|$ AT BELLE

- Tagged inclusive reconstruction of $B \to X_u l\nu$
- New idea: bin events by number of charged pions:



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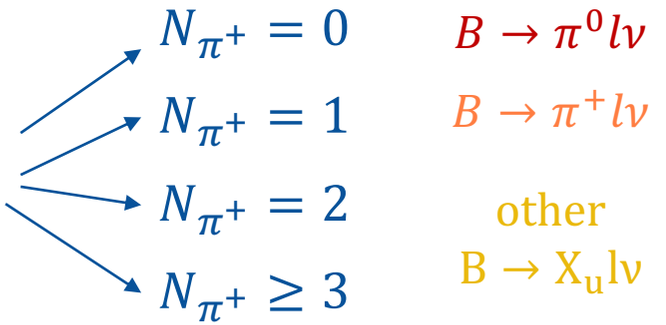

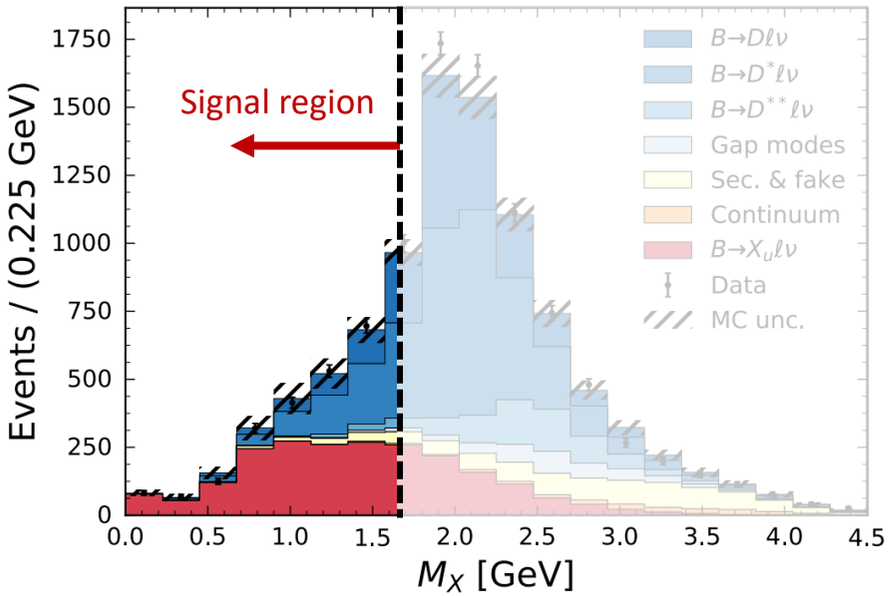

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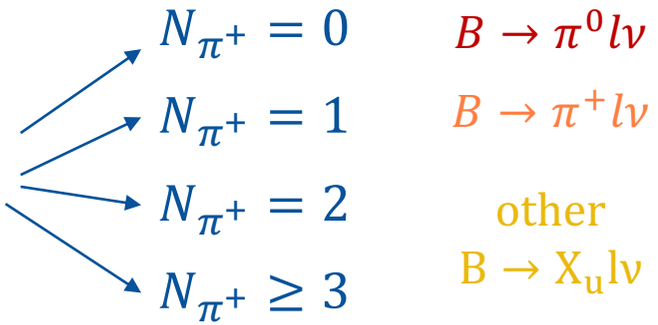

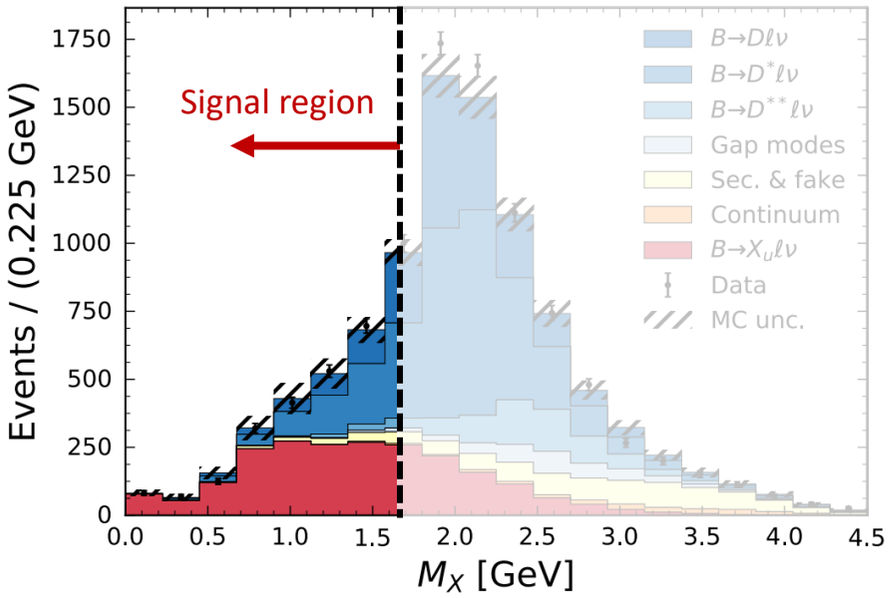

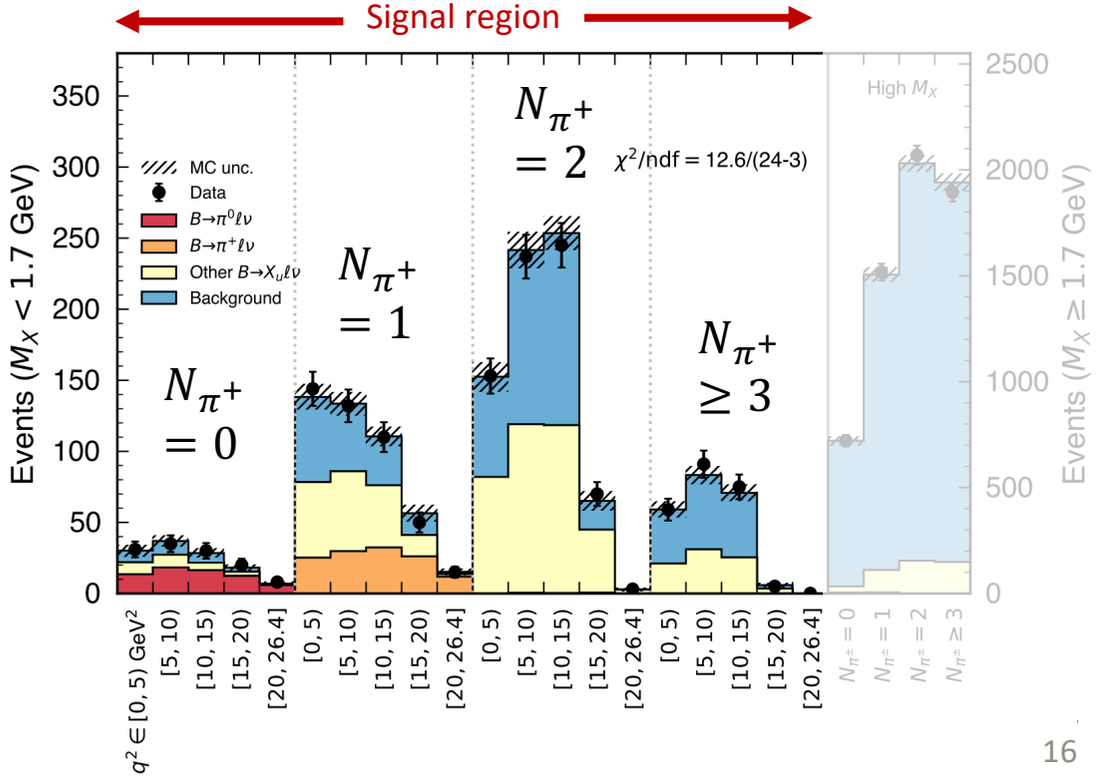

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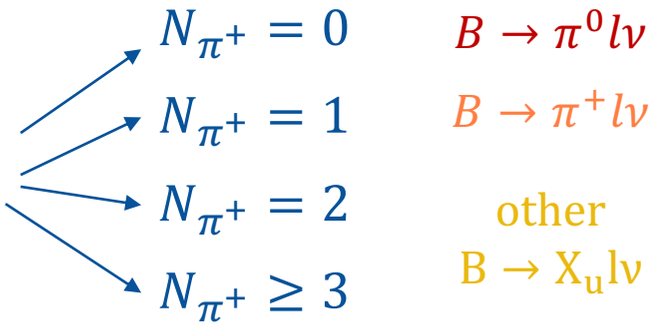
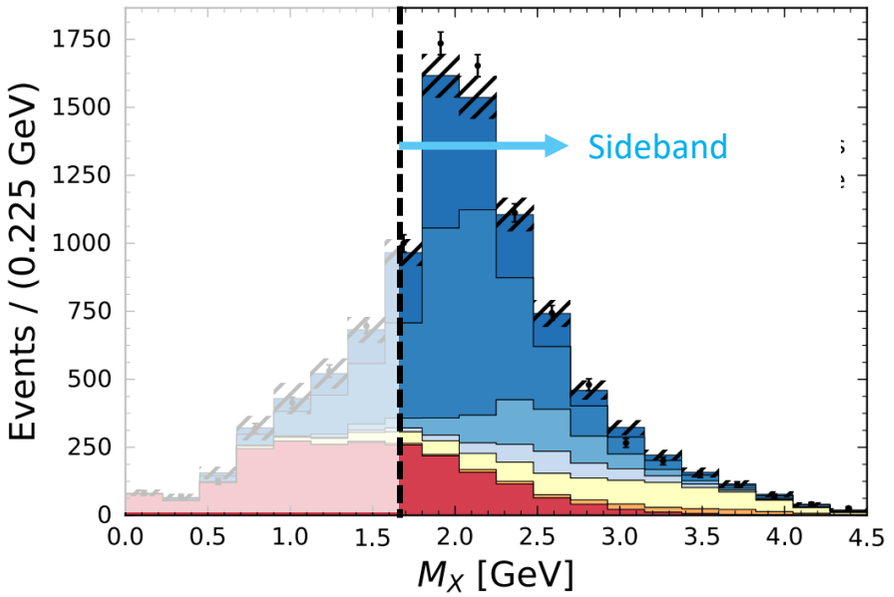
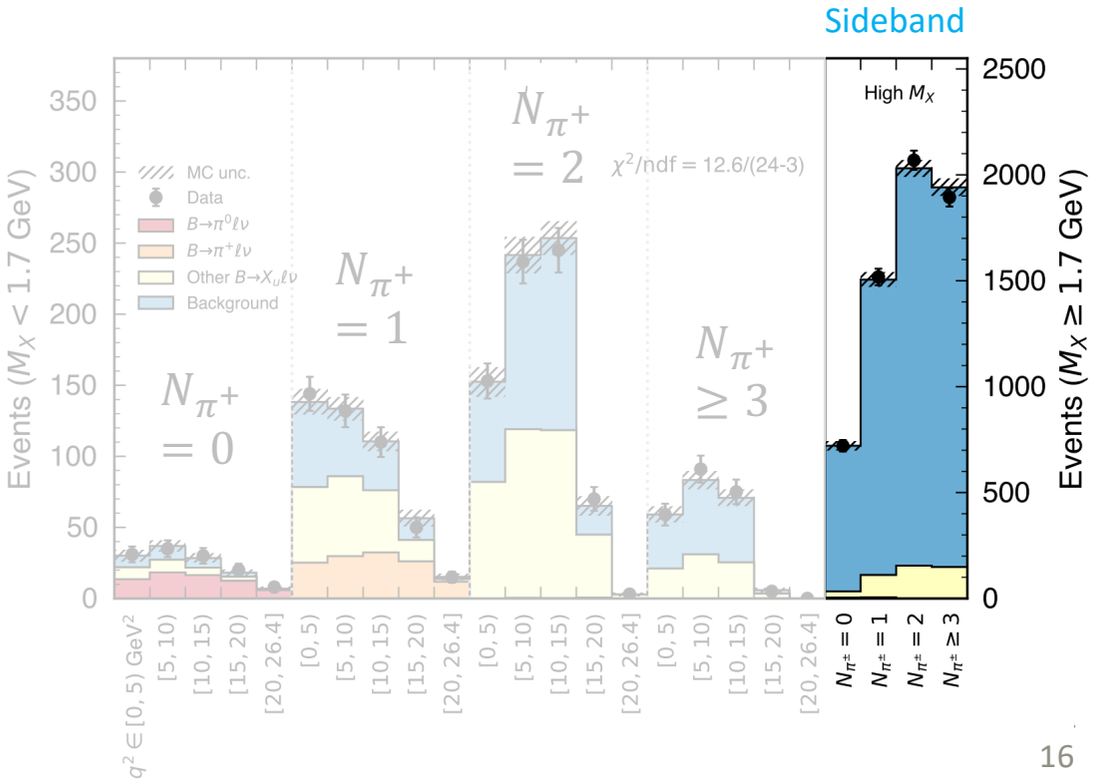




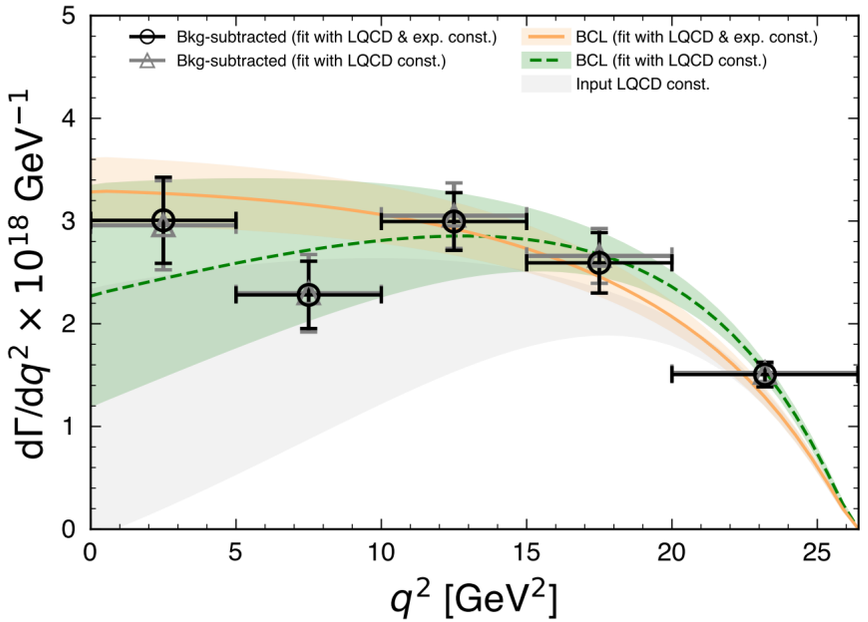
Use high M_X sideband to constrain background



TAGGED SIMULTANEOUS EXCL. AND INCL. $|V_{ub}|$ AT BELLE

Exclusive $|V_{ub}|$:

- Float BCL $B \to \pi l \nu$ FF parameters in fit with two constraining options:
  - FLAG lattice QCD Eur. Phys. J. C 82 (2022) 869
  - FLAG + experimental information



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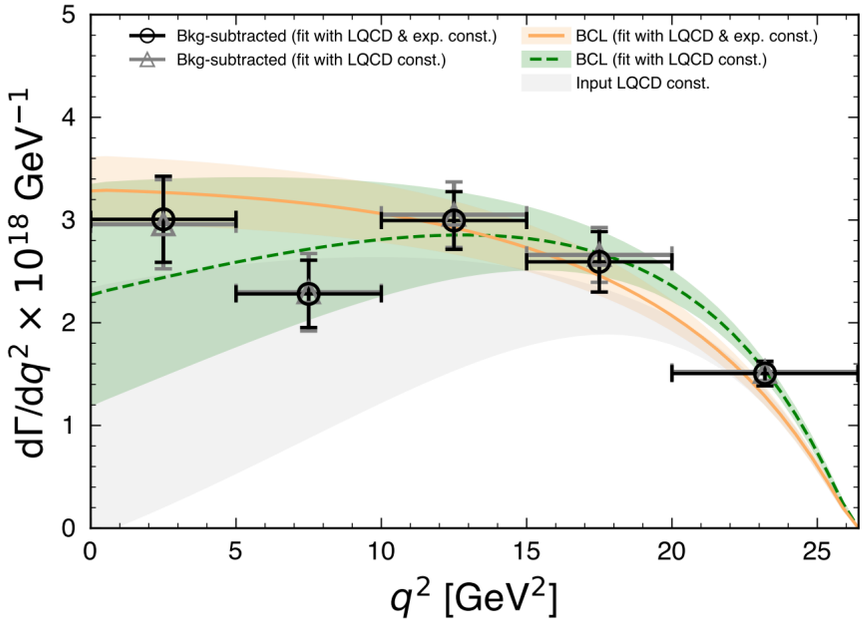

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$$|V_{ub}^{excl}| = (3.78 \pm 0.23_{stat} \pm 0.16_{syst} \pm 0.14_{theo}) \times 10^{-3}$$
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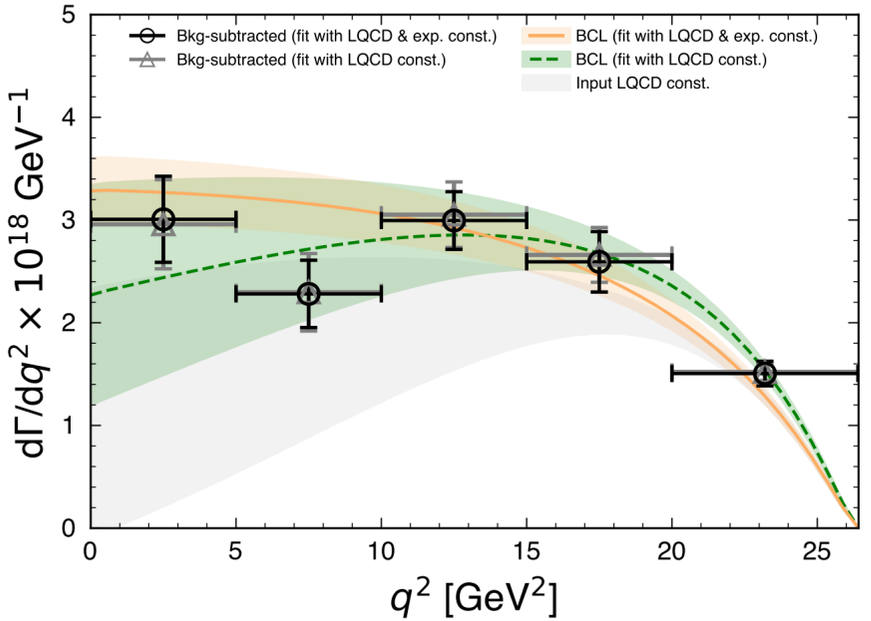

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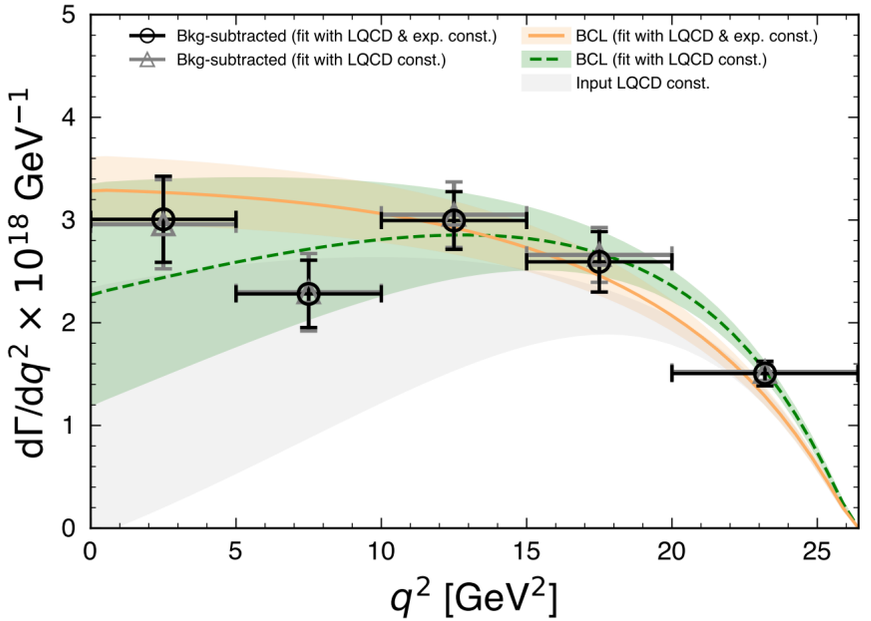
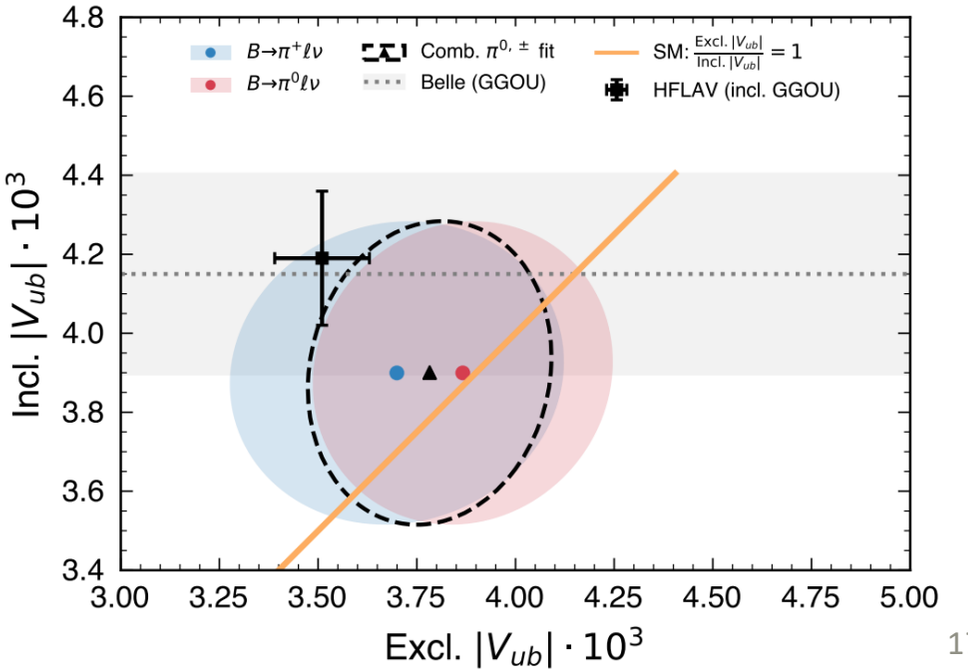


$$|V_{ub}^{excl}|/|V_{ub}^{incl}| = 0.97 \pm 0.12_{tot}$$

Agrees with expectation of 1 and within 1.1σ with the world-average



LEPTON UNIVERSALITY (LU)

$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(\mathrm{B} \to D^{(*)}l\nu)}$$

Angular observables

Lepton universality (LU) tests

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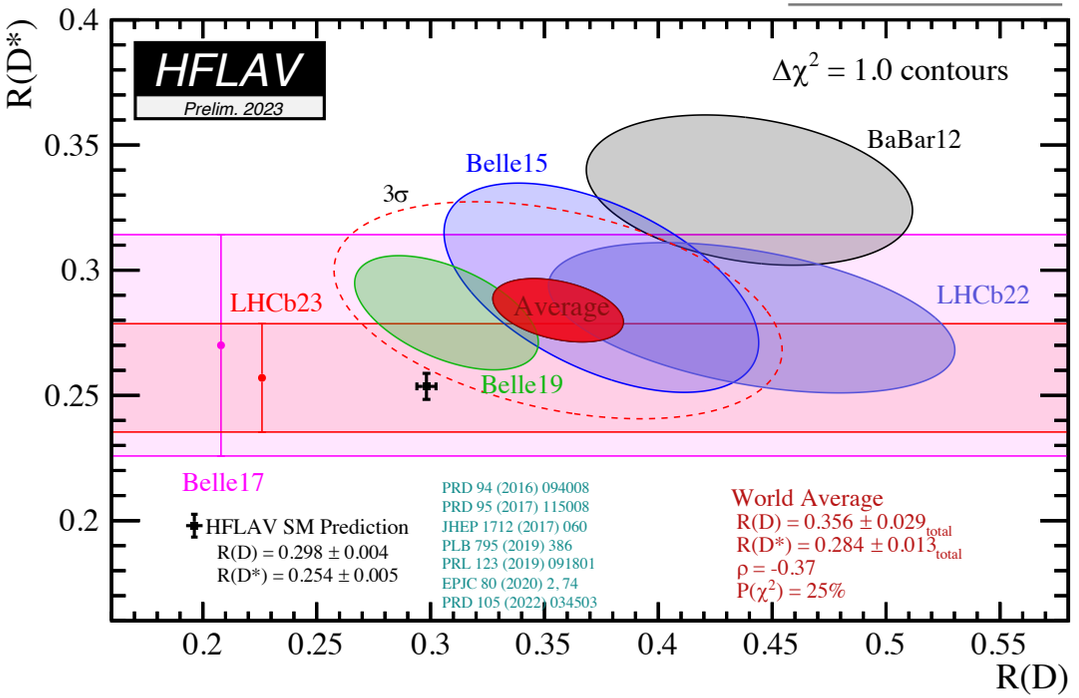
Angular observables

Lepton universality (LU) tests

Tension with SM at ≈ 3σ

arXiv:2206.07501



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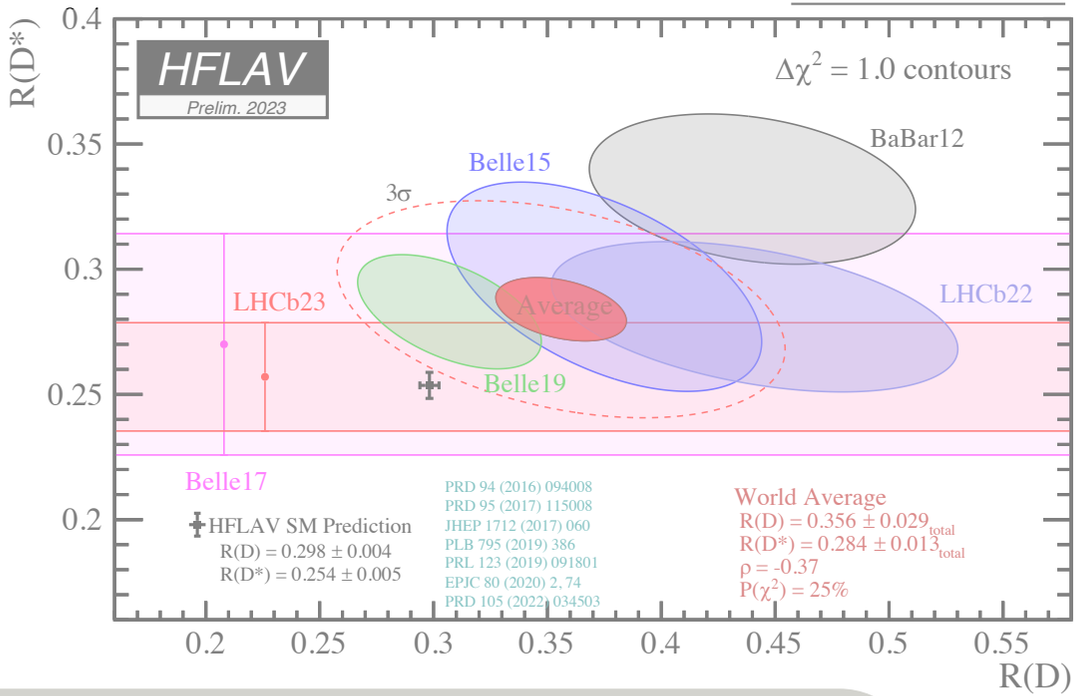


Lepton universality (LU) tests

- LU test in tagged $B \to Xl\nu$ at Belle II
- Tagged $B \to D^{(*)}\pi(\pi)l\nu$ at Belle
- Angular observables in tagged $B \to D^{*}l\nu$ at Belle II

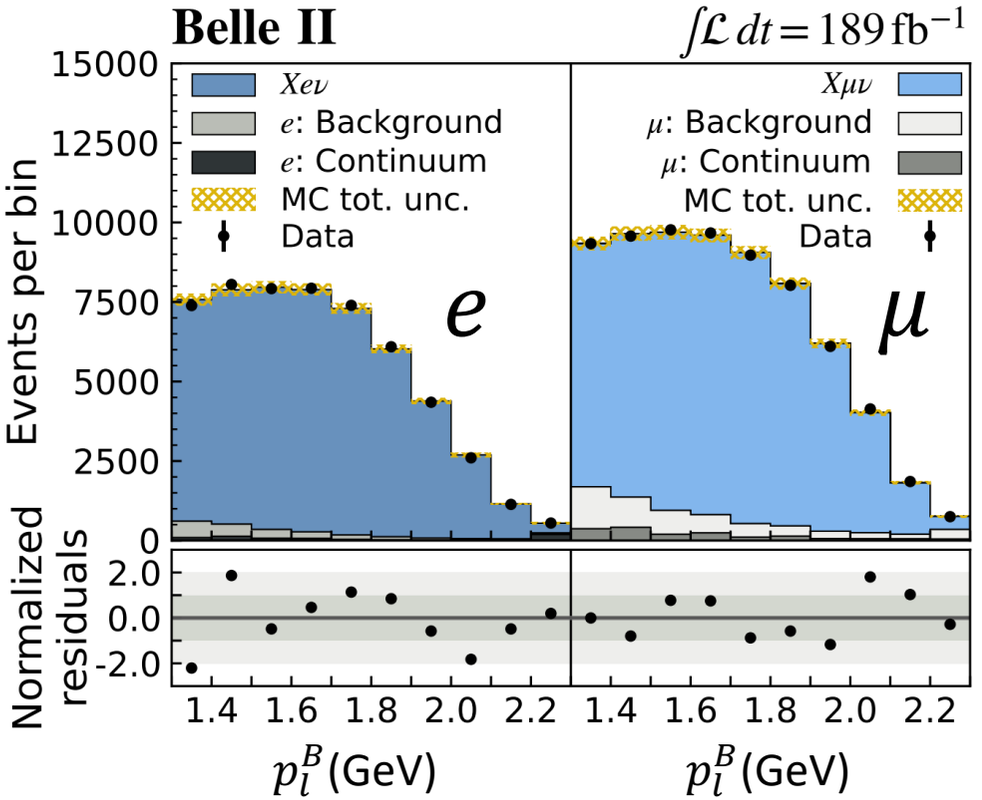
Accepted by PRL, arXiv:2301.08266

LU TEST IN $B \to Xl\nu$ AT BELLE II

- Inclusive test of LFU in tagged semileptonic B decays

$$R(X_{e/\mu}) = \frac{\mathcal{B}(B \to Xe\nu)}{\mathcal{B}(\mathrm{B} \to X\mu\nu)}$$

- Fit lepton momentum in B frame ($p_l^B > 1.3$ GeV)
  - Constrain continuuum + background from sideband



Accepted by PRL, arXiv:2301.08266

LFU TEST IN $B \to Xl\nu$ AT BELLE II

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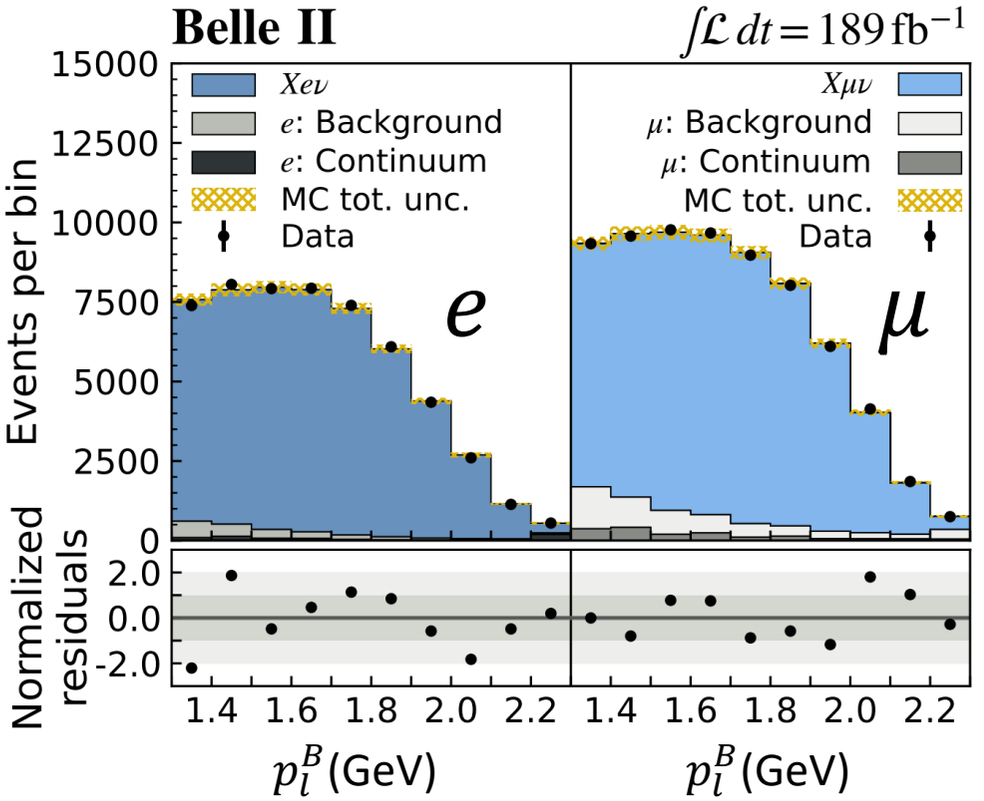
$$R(X_{e/\mu}) = \frac{\mathcal{B}(B \to Xe\nu)}{\mathcal{B}(\mathrm{B} \to X\mu\nu)}$$

- Fit lepton momentum in B frame ($p_l^B > 1.3$ GeV)
  - Constrain continuuum + background from sideband

$$\mathrm{R}(\mathrm{X_{e/\mu}}) = 1.007 \pm 0.009_{\mathrm{stat}} \pm 0.019_{\mathrm{syst}}$$

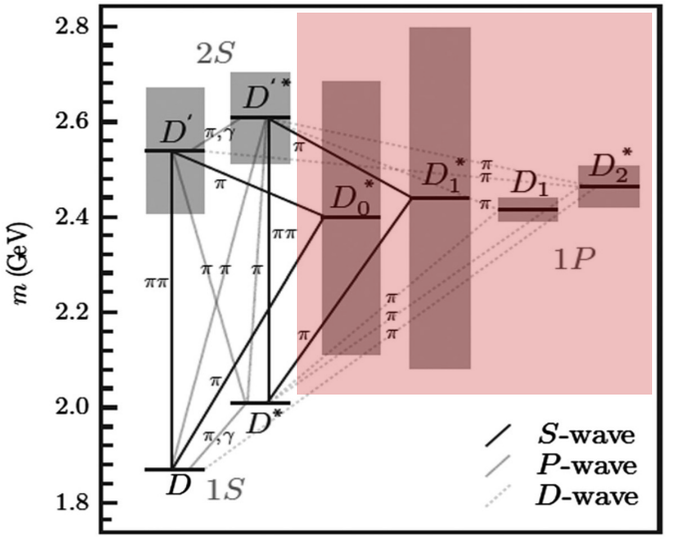
- Compatible with SM prediction arXiv:2207.03432
- Most precise BF-based LFU test with semileptonic decays



Source	Uncertainty [%]
Sample size	0.9
Lepton identification	1.9
$X\,\ell\,\nu$ branching fractions	0.2
$X_c\,\ell\,\nu$ form factors	0.1
Total	2.1

TAGGED $B \to D^{(*)}\pi(\pi)l\nu$ AT BELLE

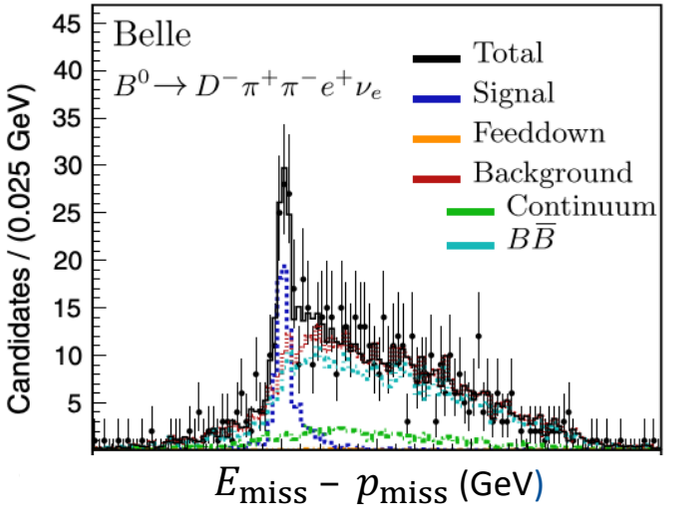
Phys. Rev. D 107 (2023), 092003



Phys. Rev. D 85 (2012), 094033

- Large uncertainties in $R(D^{(*)})$ measurements from $B \to D^{**}l\nu$
  - 4 orbitally excited charm states that decay into $D^{(*)}\pi$ or $D^{(*)}\pi\pi$
- Determine $\frac{\mathcal{B}(B\to D^{(*)}\pi(\pi)l\nu)}{\mathcal{B}(\mathrm{B}\to D^{(*)}l\nu)}$ from unbinned fits to $E_{\mathrm{miss}} - p_{\mathrm{miss}}$

One of 16 modes
fit simultaneously:



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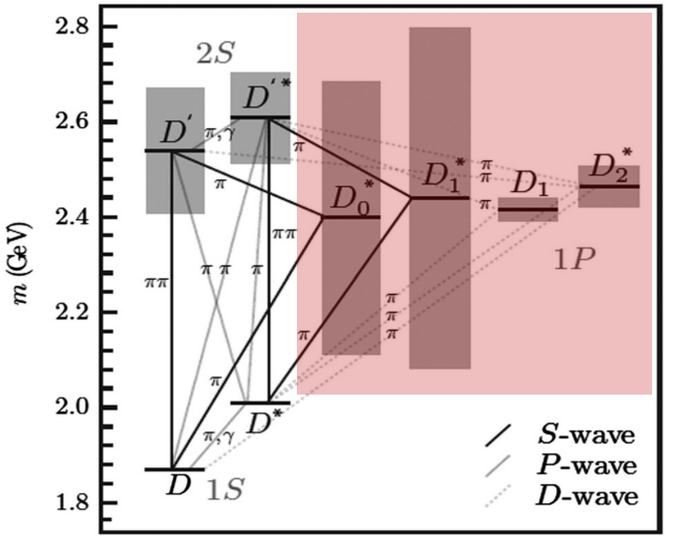
Phys. Rev. D 107 (2023), 092003



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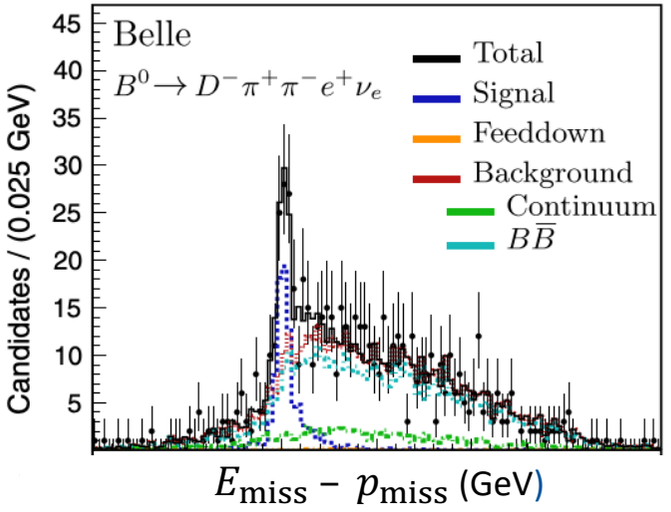
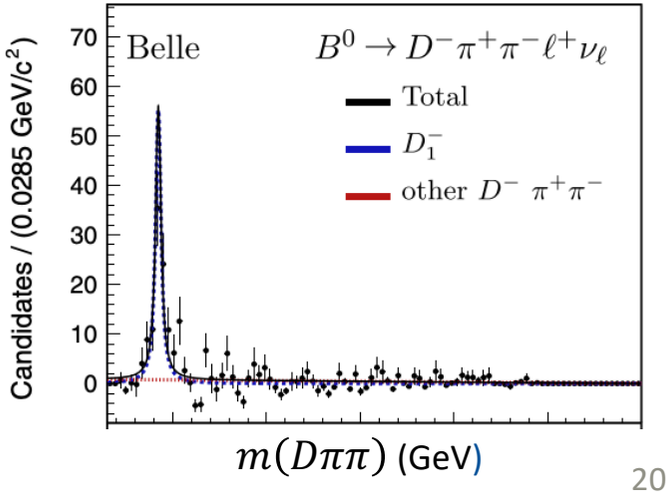


- Subtract background and extract D^{**} contributions from unbinned fit to invariant mass: $m\left(D^{(*)}\pi(\pi)\right)$
- First observation of $B \to D_1 l\nu$ with $D_1 \to D\pi\pi$
- Highest precision $\mathcal{B}(B \to D^{(*)}\pi(\pi)l\nu)$ to date



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ANGULAR ASYMMETRIES IN TAGGED $B \to D^* l\nu$ AT BELLE II

- Test light LU by measuring angular observables:

$$A_x(w) = \left(\frac{d\Gamma}{dw}\right)^{-1} \left[\int_0^1 - \int_{-1}^0\right] dx \, \frac{d^2\Gamma}{dw dx} \longrightarrow \Delta A_x = A_x^e - A_x^\mu$$

- high w
- low w
- inclusive w

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$A_{FB}(w)$: $dx \to d(\cos\theta_l)$
$S_3(w)$: $dx \to d(\cos 2\chi)$
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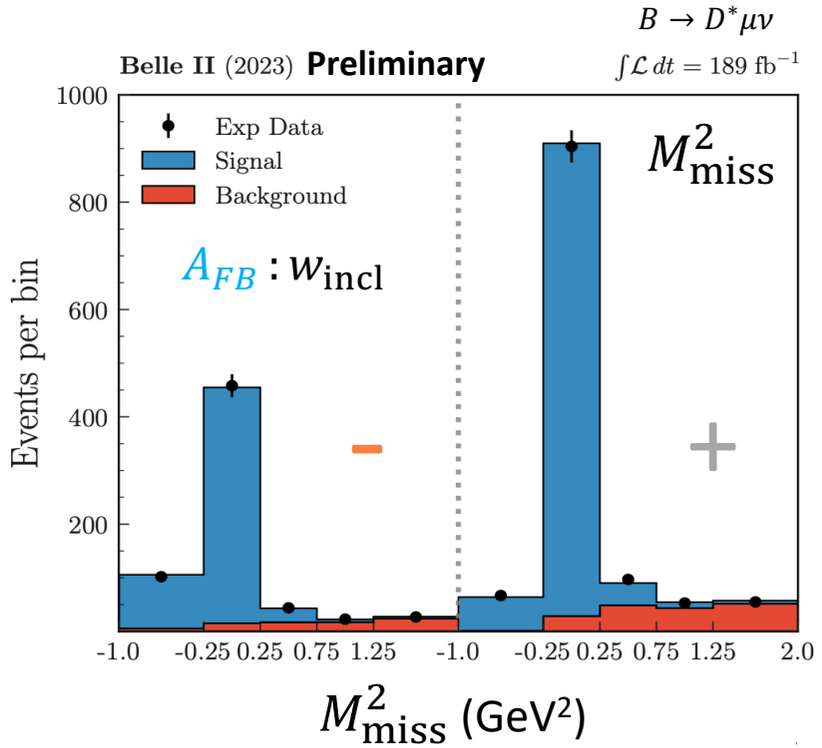

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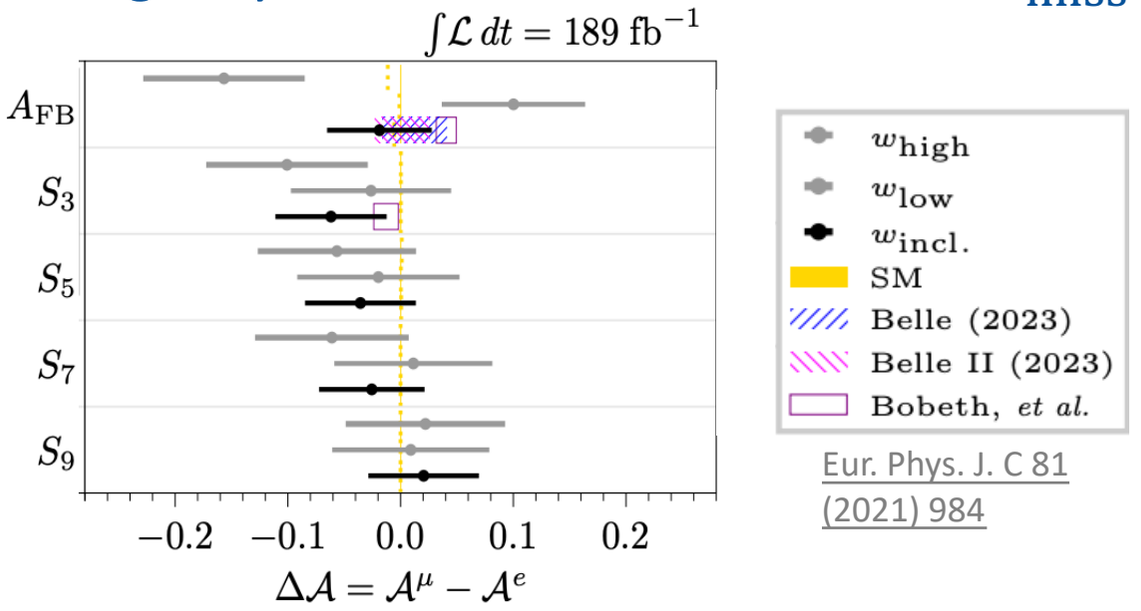
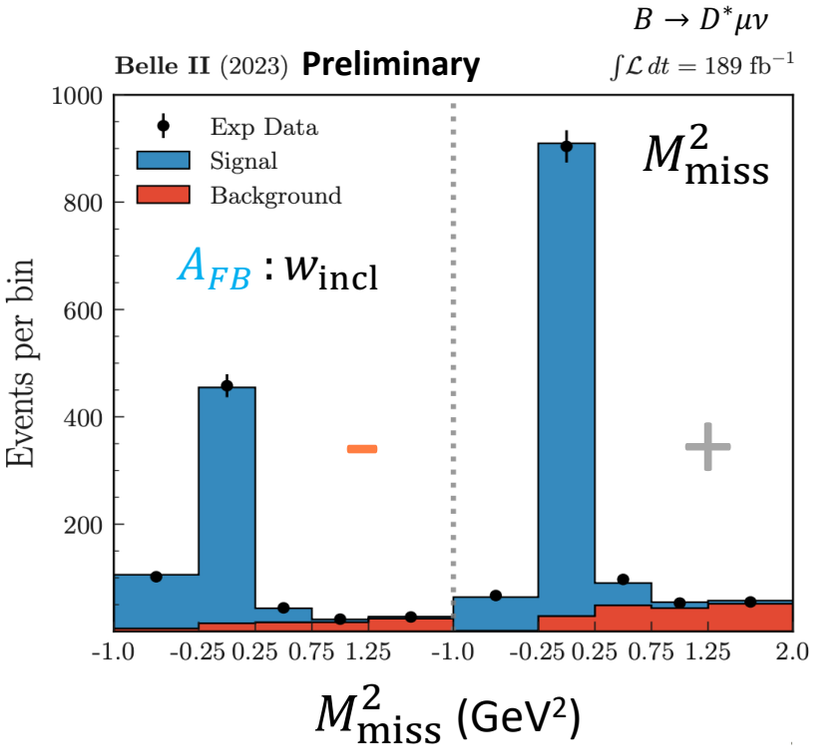


Eur. Phys. J. C 81 (2021) 984

No evidence for LU violation found



SUMMARY

Precision measurements:

- Most recent $|V_{cb}|$ results from $B \to D^* l\nu$ shift exclusive closer to inclusive average

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Interested in continuing the journey tomorrow?

Recent Belle II results on the CKM parameters $|V_{cb}|$ and $|V_{ub}|$

- Philipp Horak

Recent Belle II results on semitauonic decays and tests of lepton-flavor universality

- Peter Lewis

Thank you for your attention!

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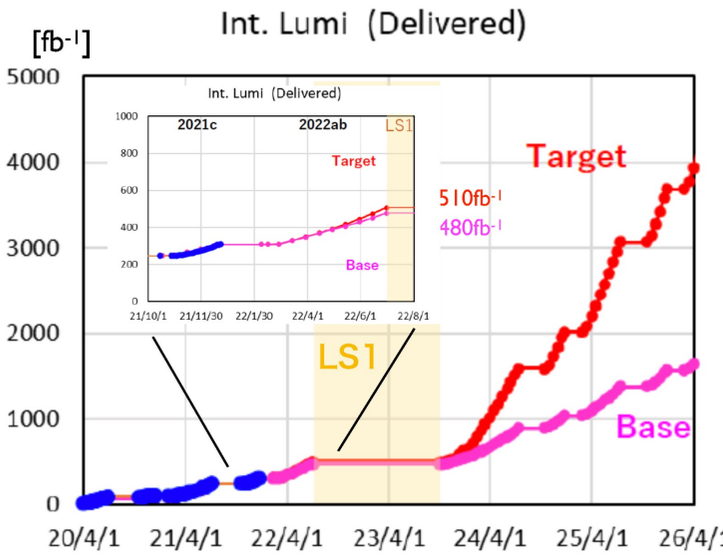
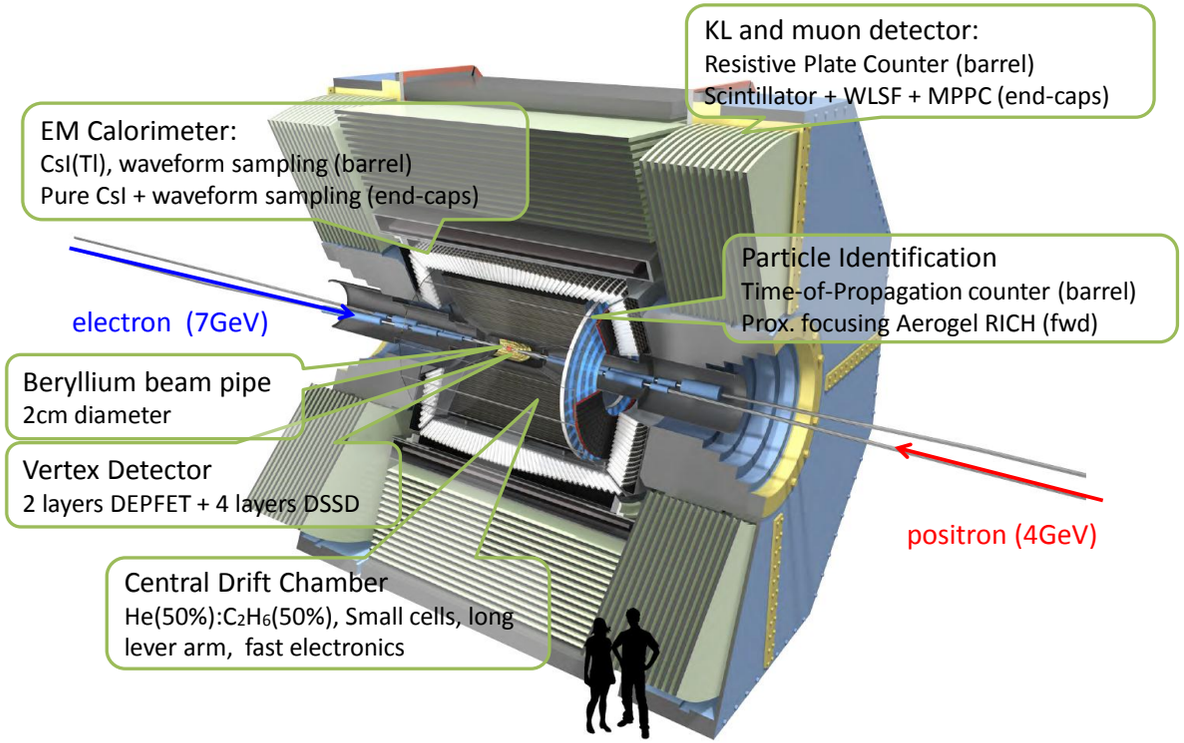
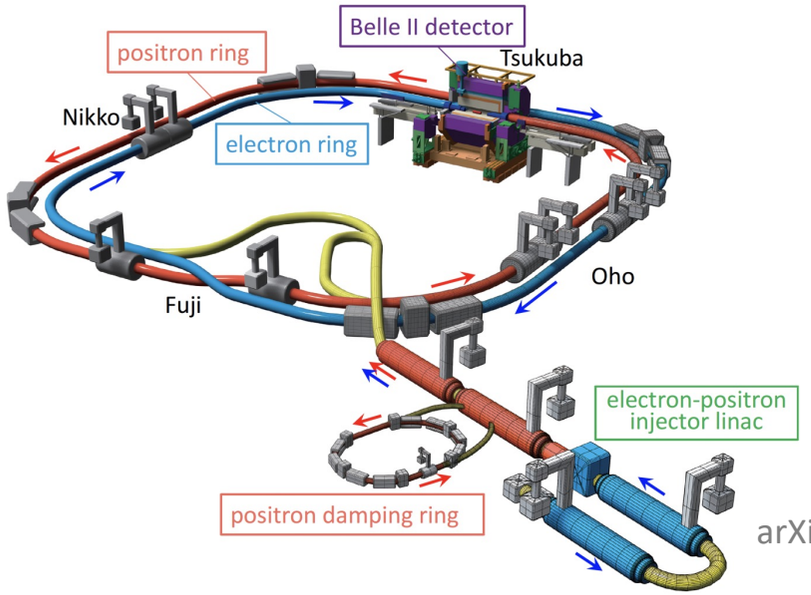
Backup

SUPERKEKB, BELLE II DETECTOR

- Now in Long Shutdown 1 (15 months)
  - Detector upgrades and beam-pipe improvement





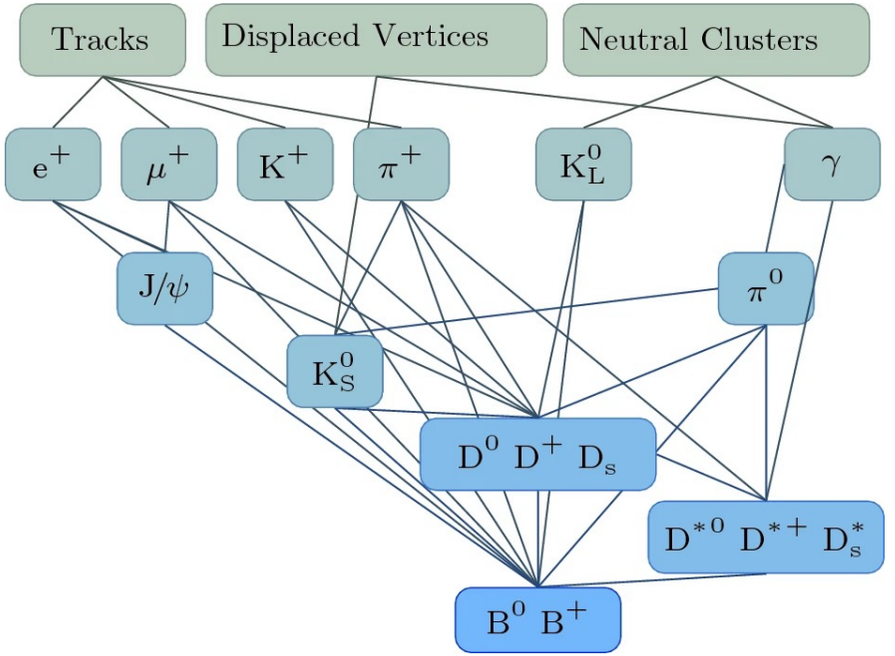


arXiv:1809.01958

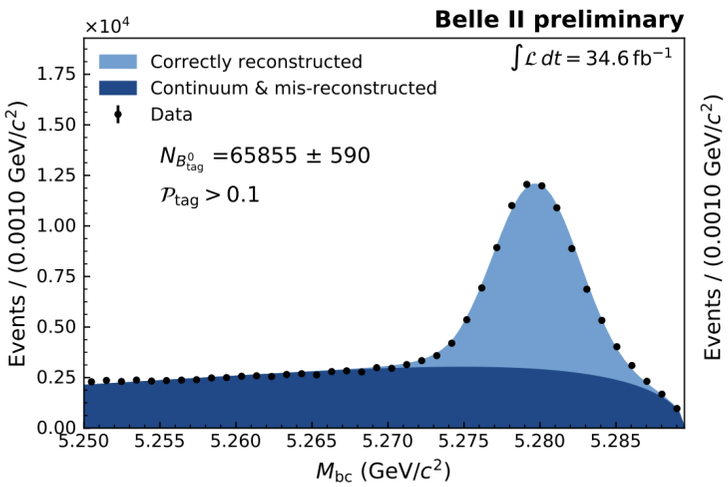
FULL EVENT INTERPRETATION (FEI)

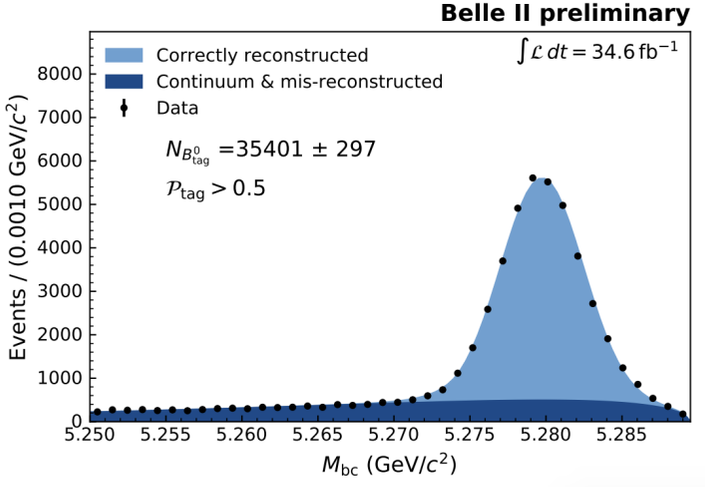
- FEI algorithm used to reconstruct B_{tag}
  - Uses ≈ 200 BDTs to reconstruct O(10000) different B decay chains
  - Assigns signal probability of being correct B_{tag}

Comput Softw Big Sci 3, 6 (2019)



arXiv:2008.060965





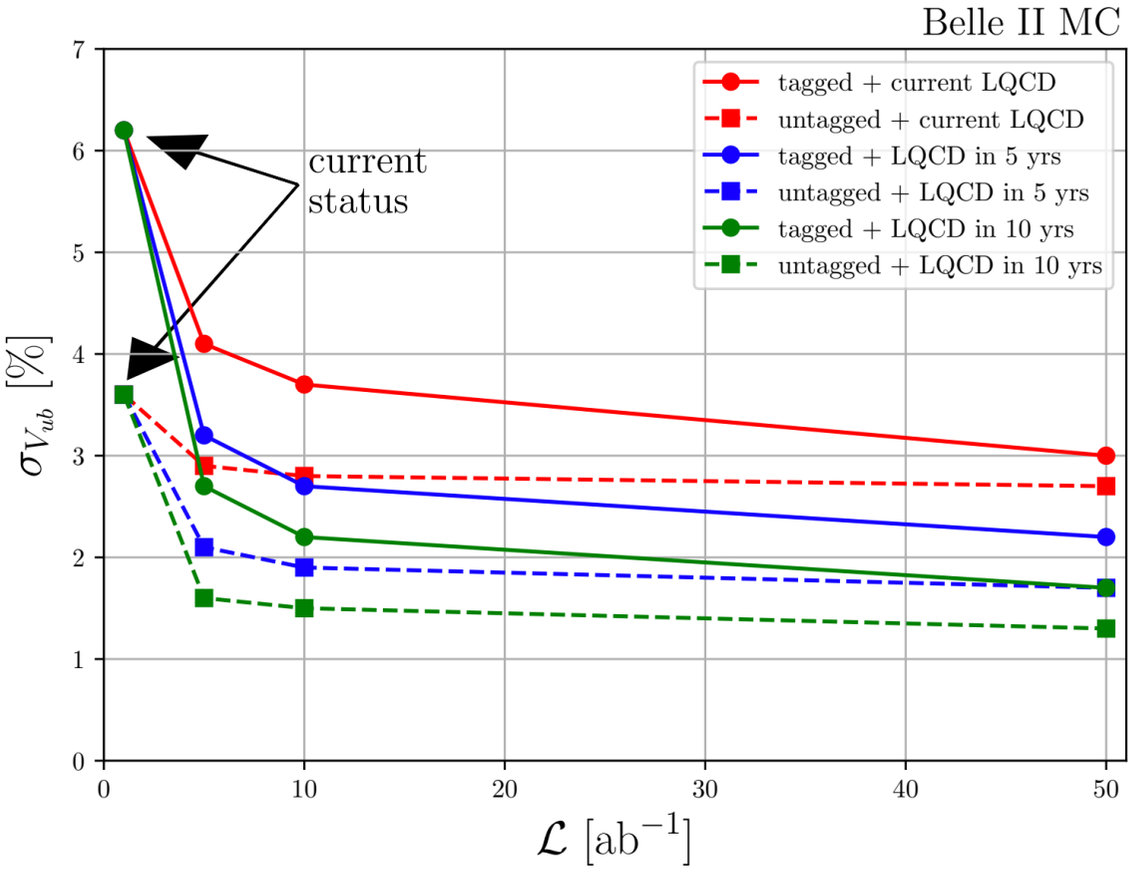
CKM MATRIX ELEMENTS

Tension:

- Most indications point to inconsistent experimental/theoretical inputs
- Cannot exclude non-SM physics

– Improvements:

- Theoretical understanding
- B→ $Xl\nu$ background modeling
- Calibration of $\mathrm{B_{tag}}$ efficiency



arXiv:2207.11275

PROJECTION AT BELLE II: R(X)

$R\left(D^{(*)}\right)$:

- Understand B→ $D^{**}l\nu$ downfeed

$R(X_{\tau/l})$

- Control inclusive background composition

arXiv:2207.11275