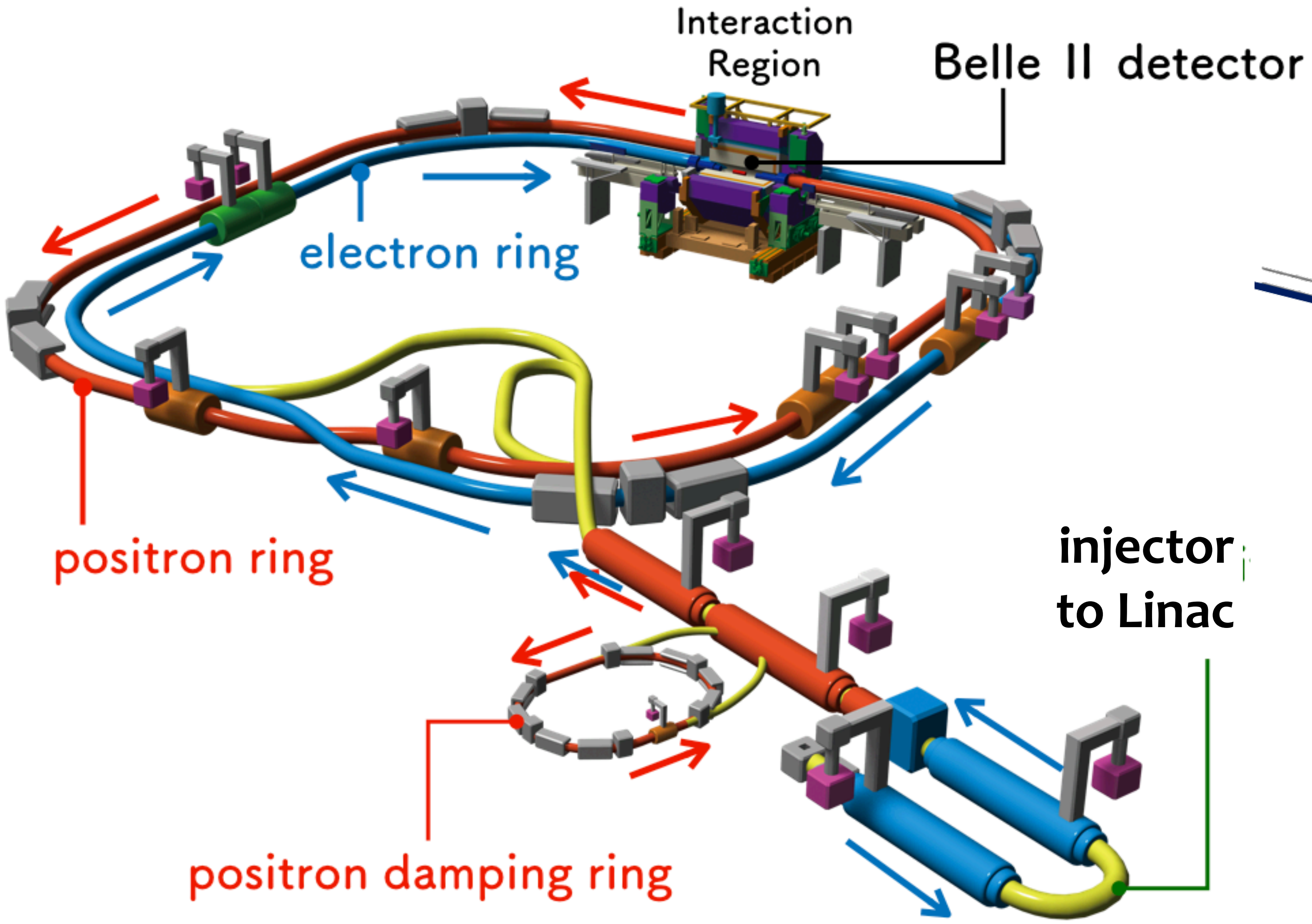
Rare B decays & other highlights from Belle II

Youngjoon Kwon (Yonsei U.)

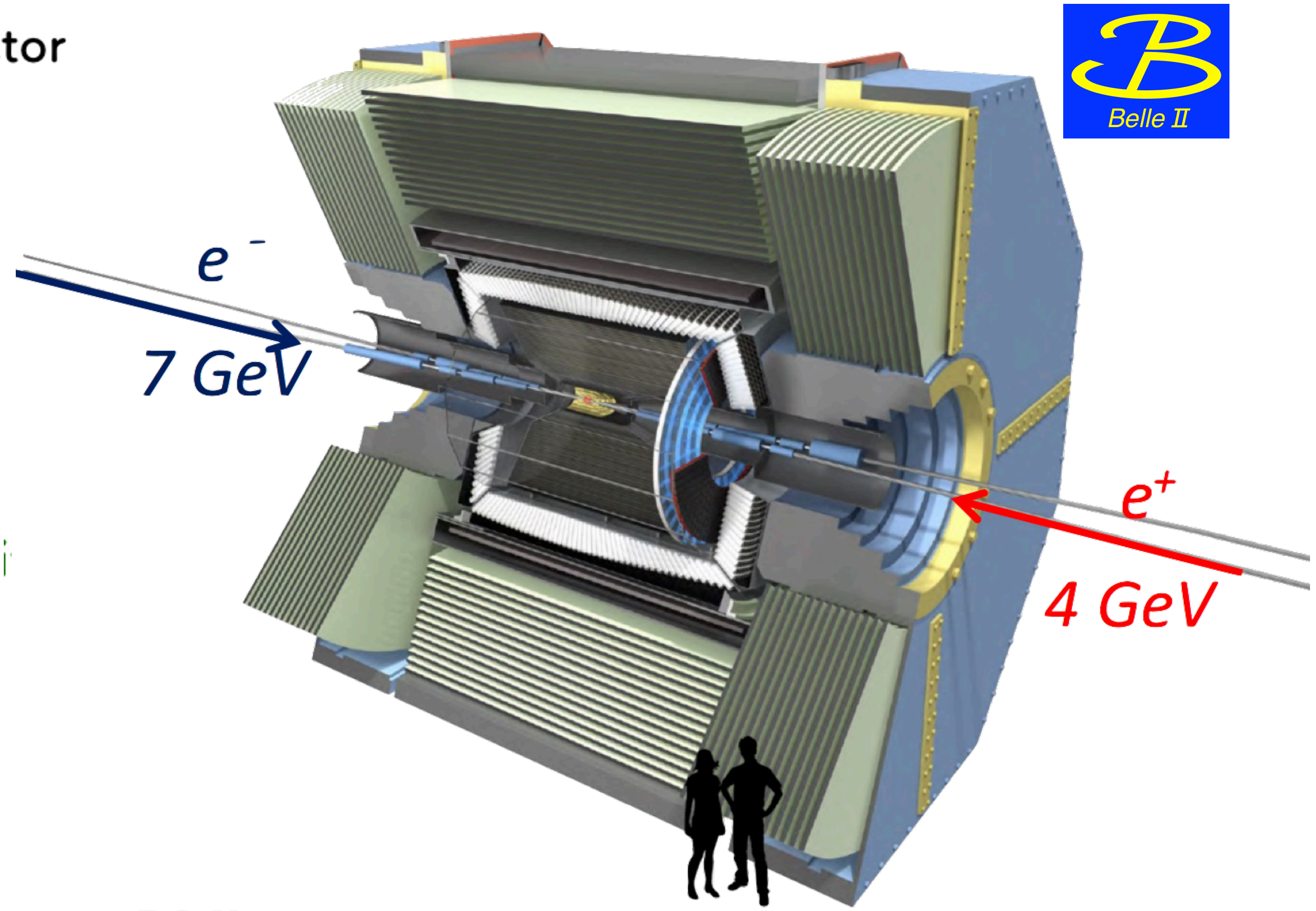
Aug. 29, 2024 @ Flavor Mini-Workshop

Belle II basics

SuperKEKB



Belle II



$$e^- \xrightarrow{7\text{ GeV}} (\star) \xleftarrow{4\text{ GeV}} e^+$$

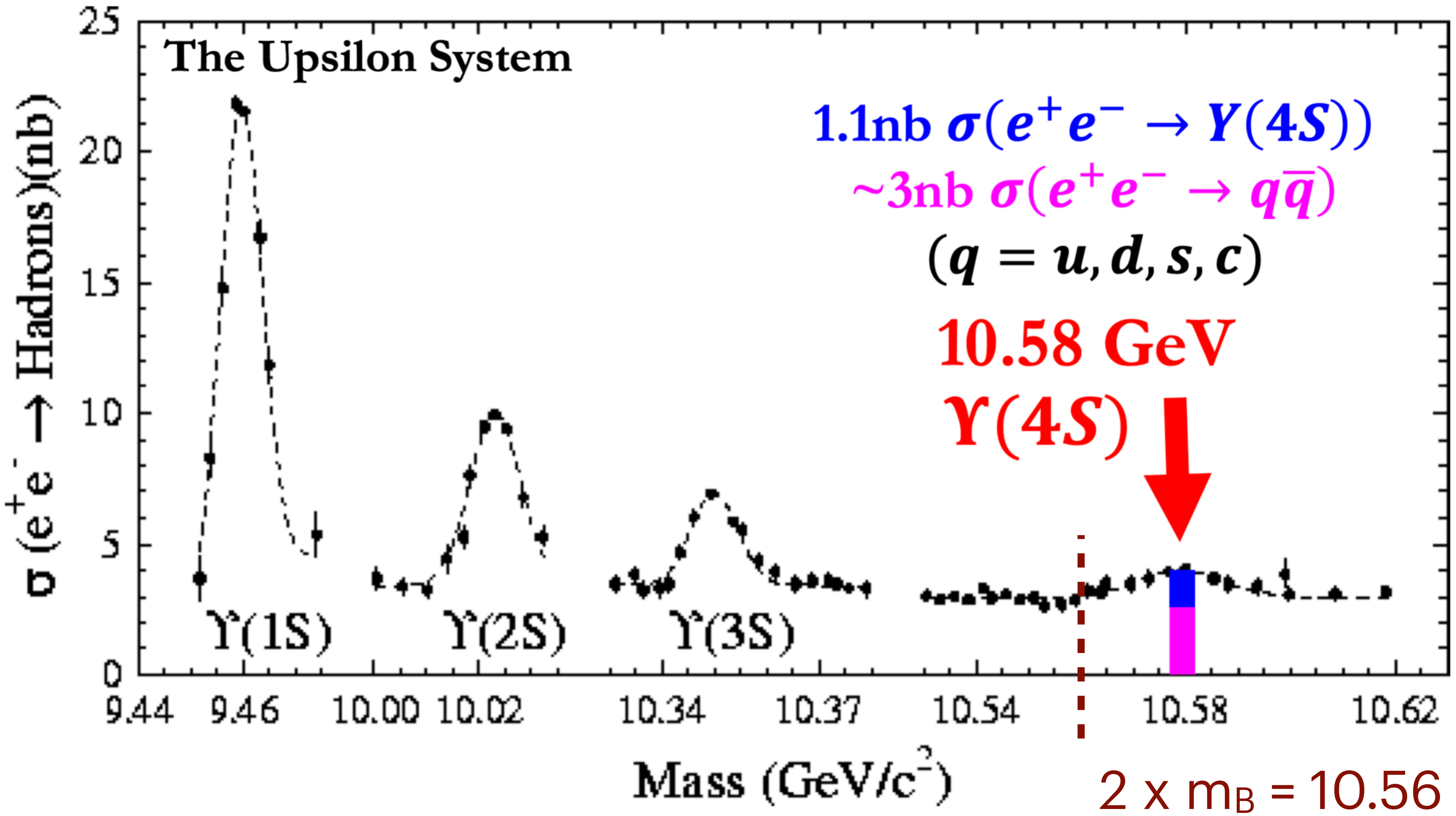
$$\sqrt{s} = 10.58\text{ GeV} = m_{\Upsilon(4S)}c^2$$

We also have data taken off-resonance as well as energy scan around $\Upsilon(5S)$

- $\mathcal{B}(\Upsilon(4S) \to B\bar{B}) > 96\%$, with $p_B^{CM} \sim 0.35$ GeV/c
- nothing else but $B\bar{B}$ in the final state

$\therefore$ if we know $(E, \vec{p})$ of one B, the other B is also constrained "B-tagging" *unique to e^+e^- B-factory*

$e^+e^- \to \Upsilon(4S)$ as a B-factory



1.1nb $\sigma(e^+e^- \to \Upsilon(4S))$

~3nb $\sigma(e^+e^- \to q\bar{q})$

$(q = u, d, s, c)$

10.58 GeV

$\Upsilon(4S)$

2 x m_B = 10.56 GeV

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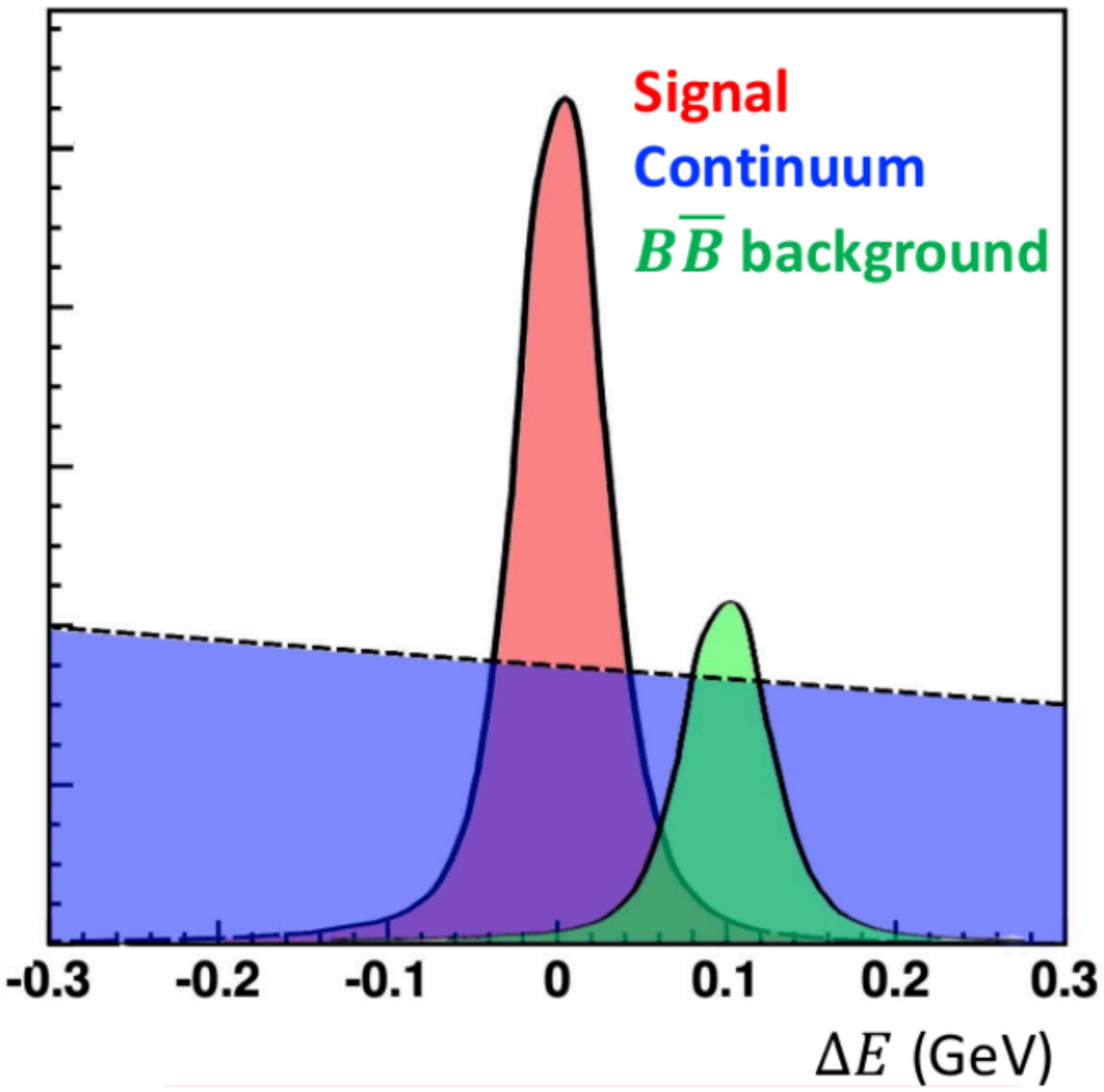
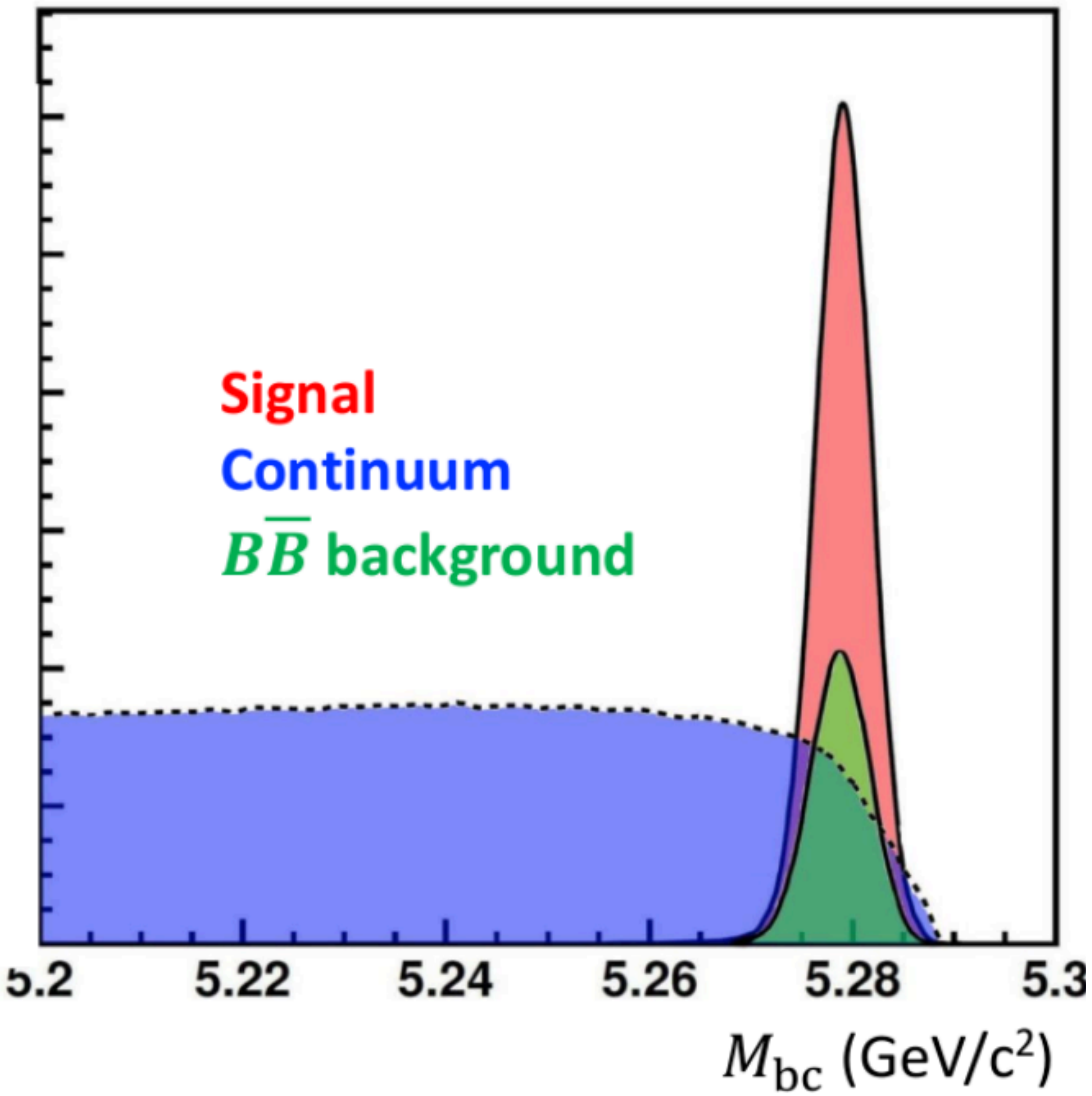
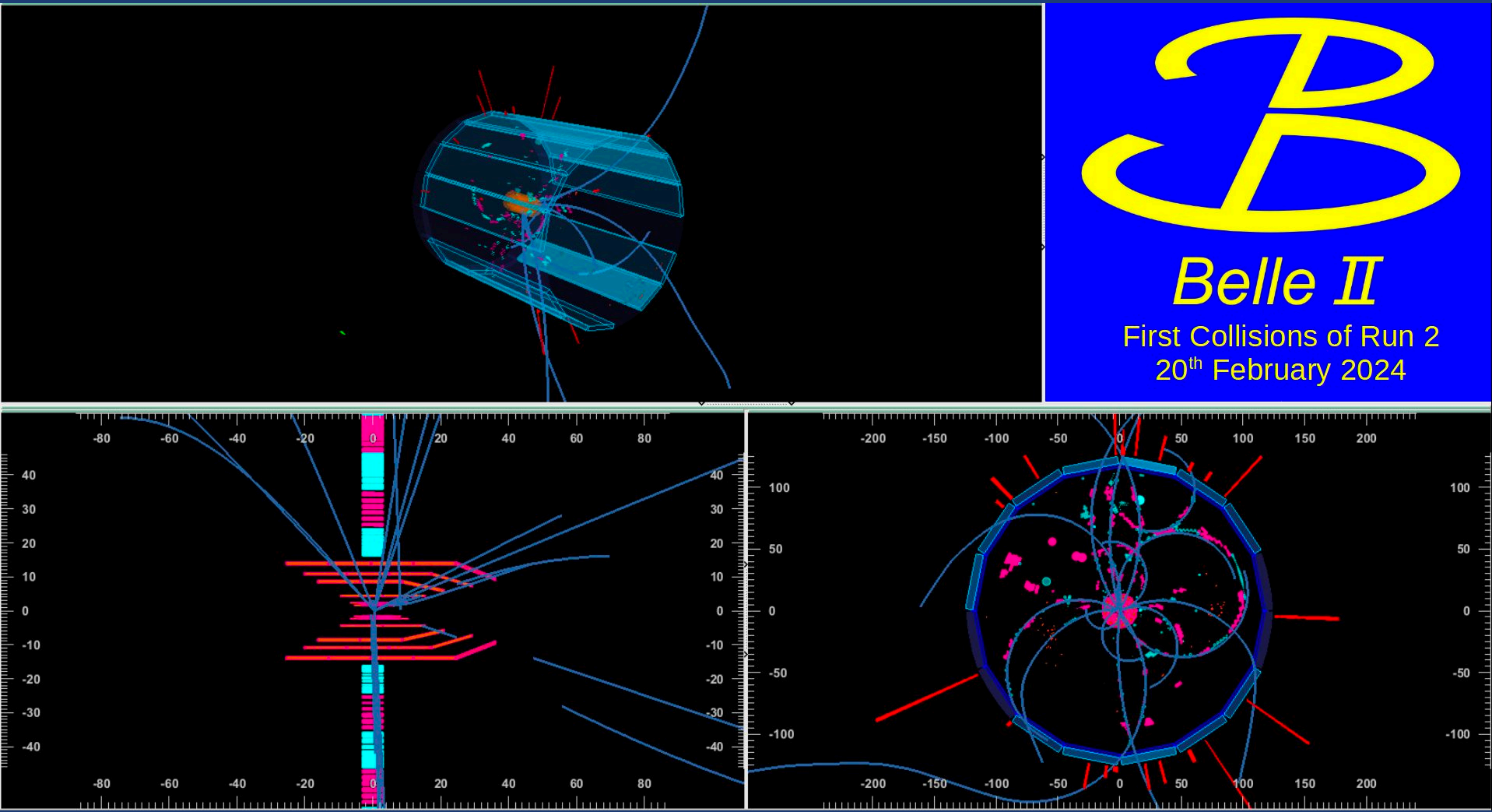
Key variables of *B* decays

$$\Delta E = E_B^* - \sqrt{s}/2$$

$$M_{bc} = \sqrt{(\sqrt{s}/2)^2 - \vec{p}_B^{*2}}$$

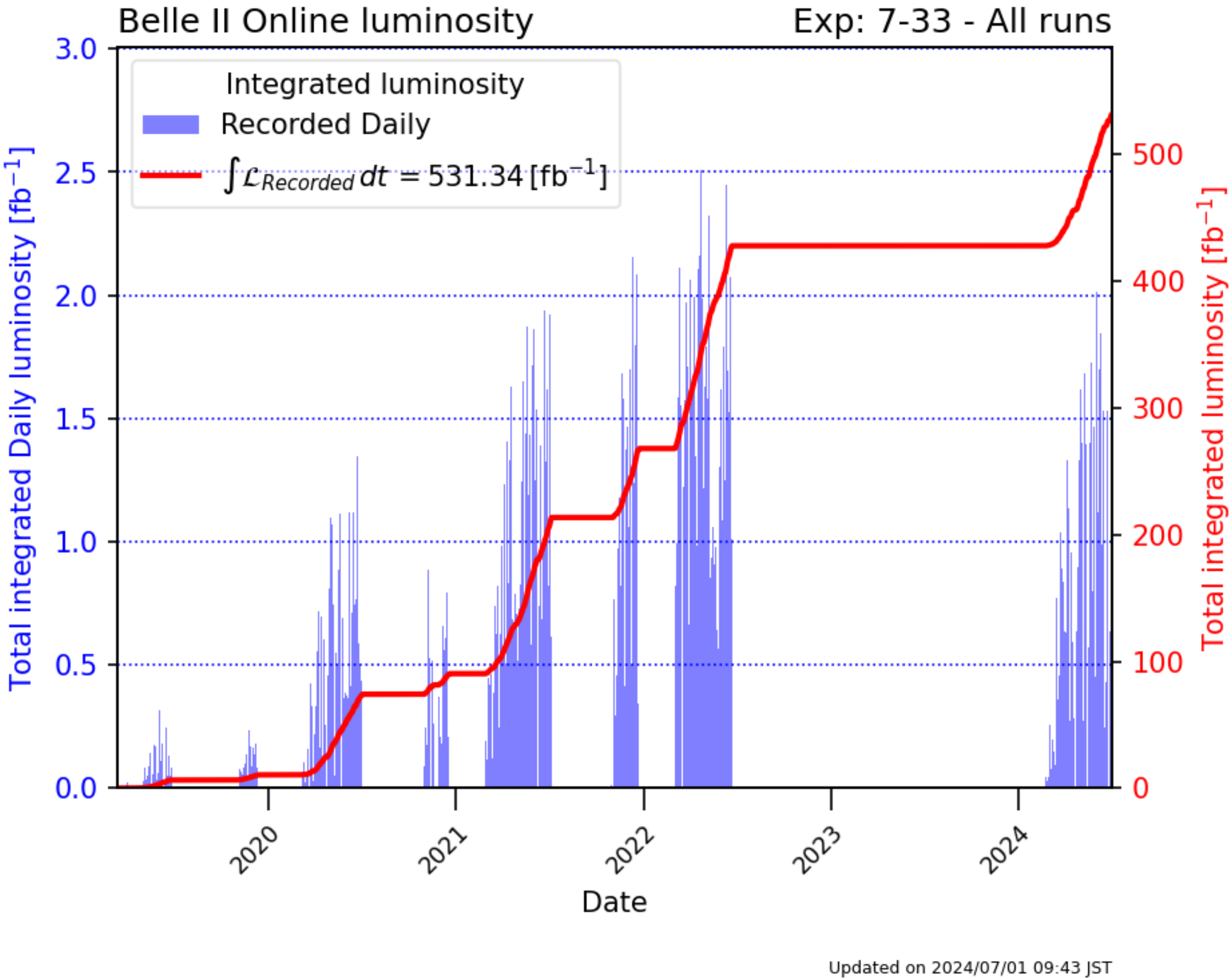






Belle II

First Collisions of Run 2
20th February 2024



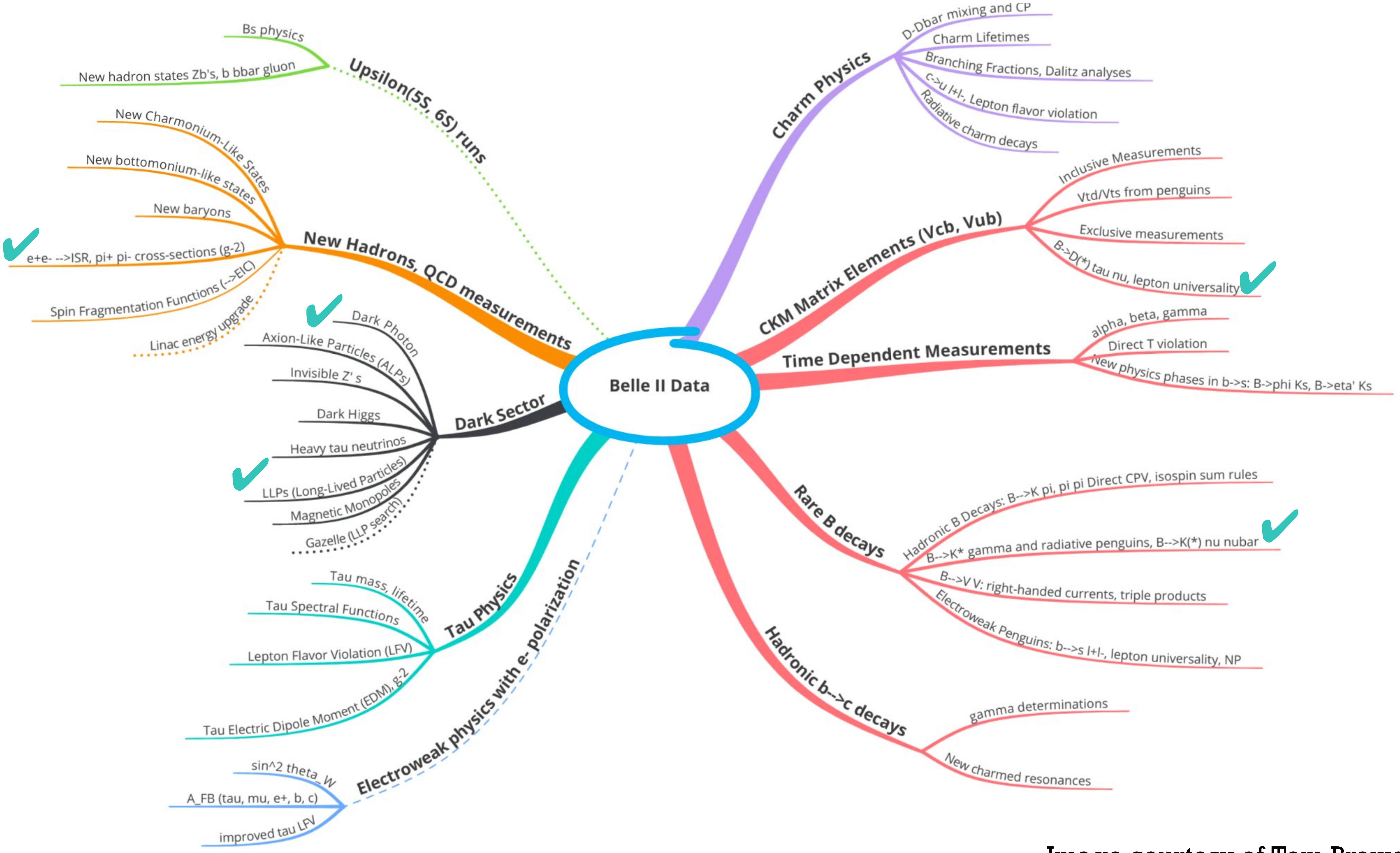
Belle (1999-2010)
Luminosity

- $\int \mathscr{L}_{\text{total}} = 1039\ \text{fb}^{-1}$

  $980\ \text{fb}^{-1}$ for Ξ_c^0

- $\int \mathscr{L}_{\Upsilon(4S)} = 711\ \text{fb}^{-1}$

Belle II Physics Mind-map



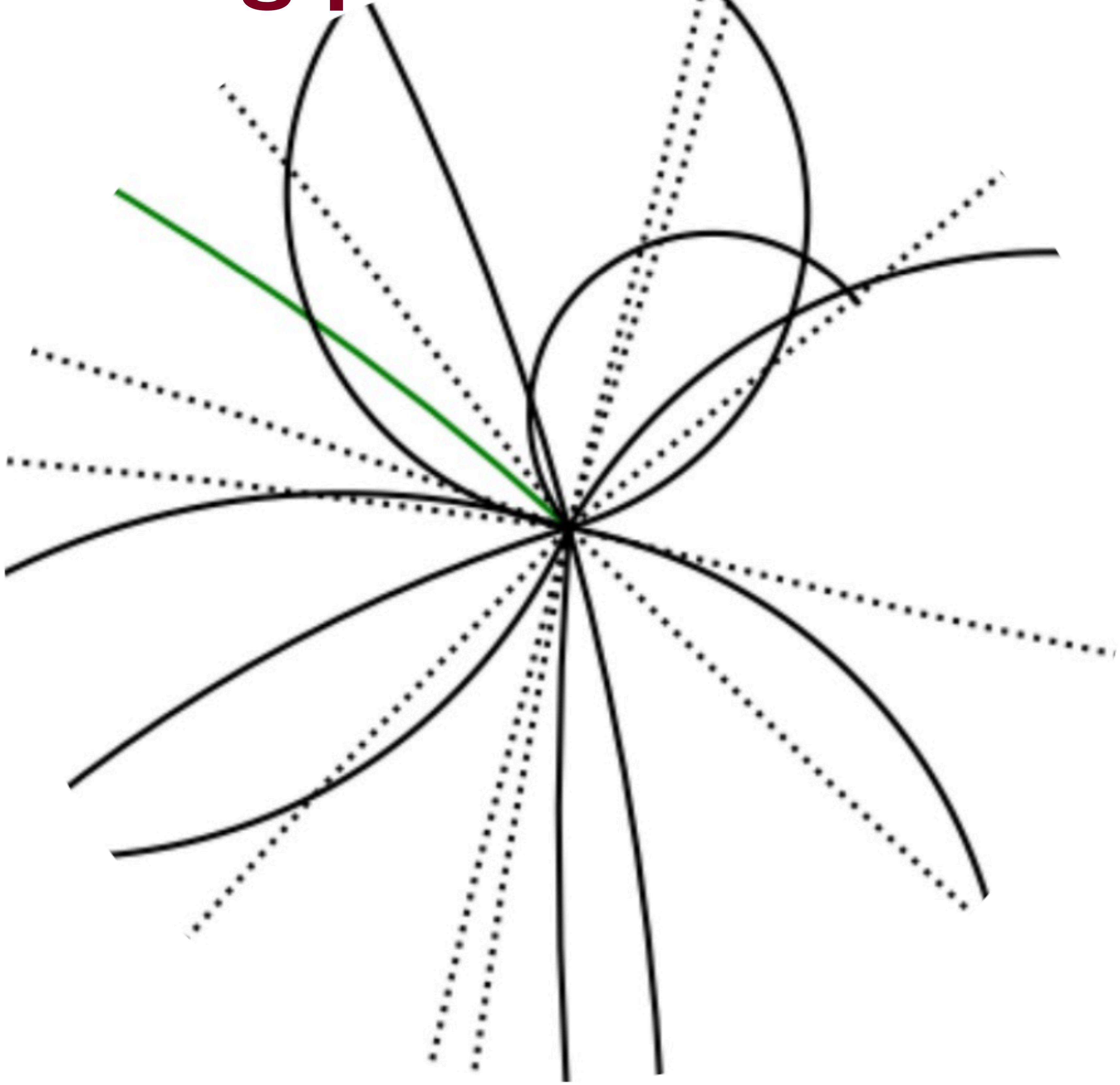
- Belle II Data
  - Upsilon(5S, 6S) runs
    - Bs physics
    - New hadron states Zb's, b bbar gluon
  - New Hadrons, QCD measurements
    - New Charmonium-Like States
    - New bottomonium-like states
    - New baryons
    - ✓ e+e- -->ISR, pi+ pi- cross-sections (g-2)
    - Spin Fragmentation Functions (-->EIC)
    - Linac energy upgrade
  - Dark Sector
    - ✓ Dark Photon
    - Axion-Like Particles (ALPs)
    - Invisible Z' s
    - Dark Higgs
    - Heavy tau neutrinos
    - ✓ LLPs (Long-Lived Particles)
    - Magnetic Monopoles
    - Gazelle (LLP search)
  - Tau Physics
    - Tau mass, lifetime
    - Tau Spectral Functions
    - Lepton Flavor Violation (LFV)
    - Tau Electric Dipole Moment (EDM), g-2
  - Electroweak physics with e- polarization
    - sin^2 theta_W
    - A_FB (tau, mu, e+, b, c)
    - improved tau LFV
  - Charm Physics
    - D-Dbar mixing and CP
    - Charm Lifetimes
    - Branching Fractions, Dalitz analyses
    - c->u l+l-, Lepton flavor violation
    - Radiative charm decays
  - CKM Matrix Elements (Vcb, Vub)
    - Inclusive Measurements
    - Vtd/Vts from penguins
    - Exclusive measurements
    - B->D(*) tau nu, lepton universality ✓
  - Time Dependent Measurements
    - alpha, beta, gamma
    - Direct T violation
    - New physics phases in b->s: B->phi Ks, B->eta' Ks
  - Rare B decays
    - Hadronic B Decays: B-->K pi, pi pi Direct CPV, isospin sum rules
    - B-->K* gamma and radiative penguins, B-->K(*) nu nubar ✓
    - B-->V V: right-handed currents, triple products
    - Electroweak Penguins: b-->s l+l-, lepton universality, NP
  - Hadronic b-->c decays
    - gamma determinations
    - New charmed resonances

Image courtesy of Tom Browder

FEI

To handle a missing particle at Belle II

- $e^+e^- \to \Upsilon(4S) \to B\overline{B}$
  - only two B mesons in the final state
  - Since the initial state is clearly determined, fully accounting one B ($B_{\rm tag}$) makes it possible to constrain the accompanying B ($B_{\rm sig}$)
  - Having a single missing particle (e.g. ν) is usually as clean as getting all particles measured
  - The price to pay is a big drop of efficiency ($< \mathcal{O}(1\%)$)



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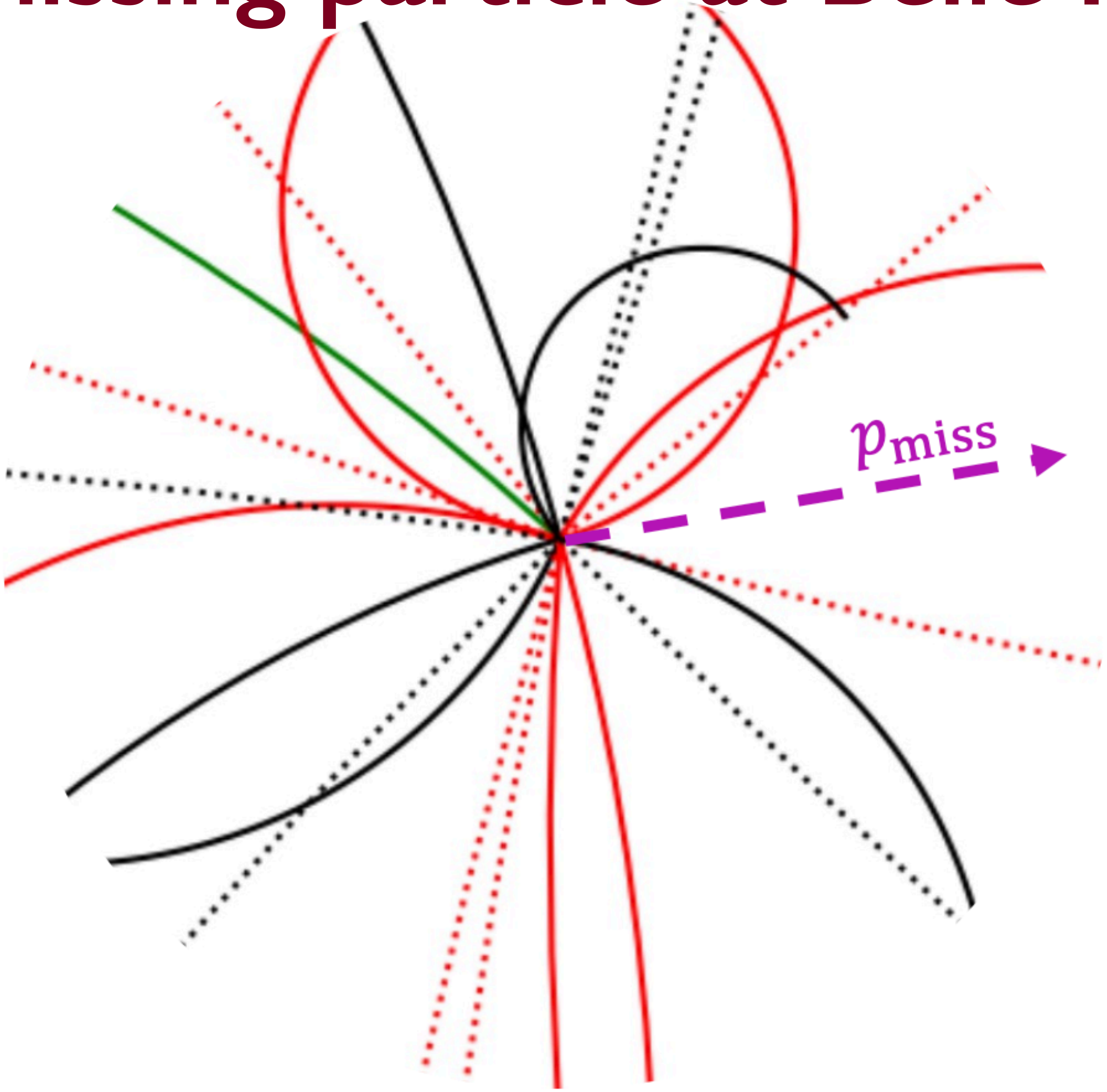
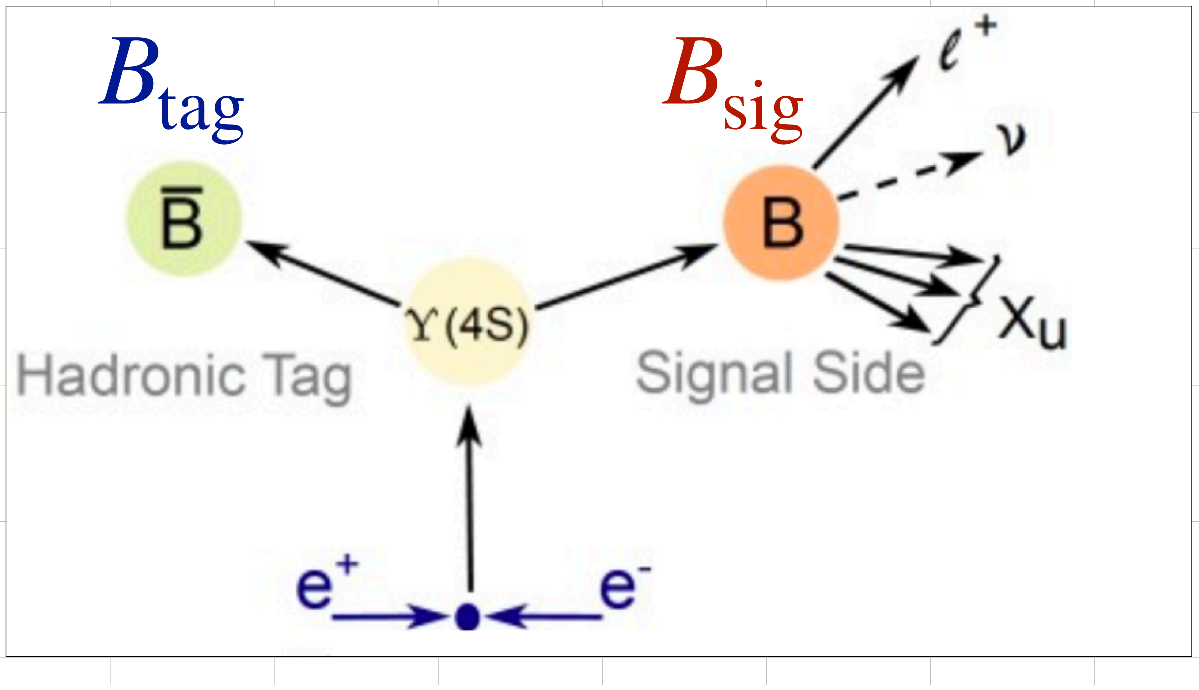


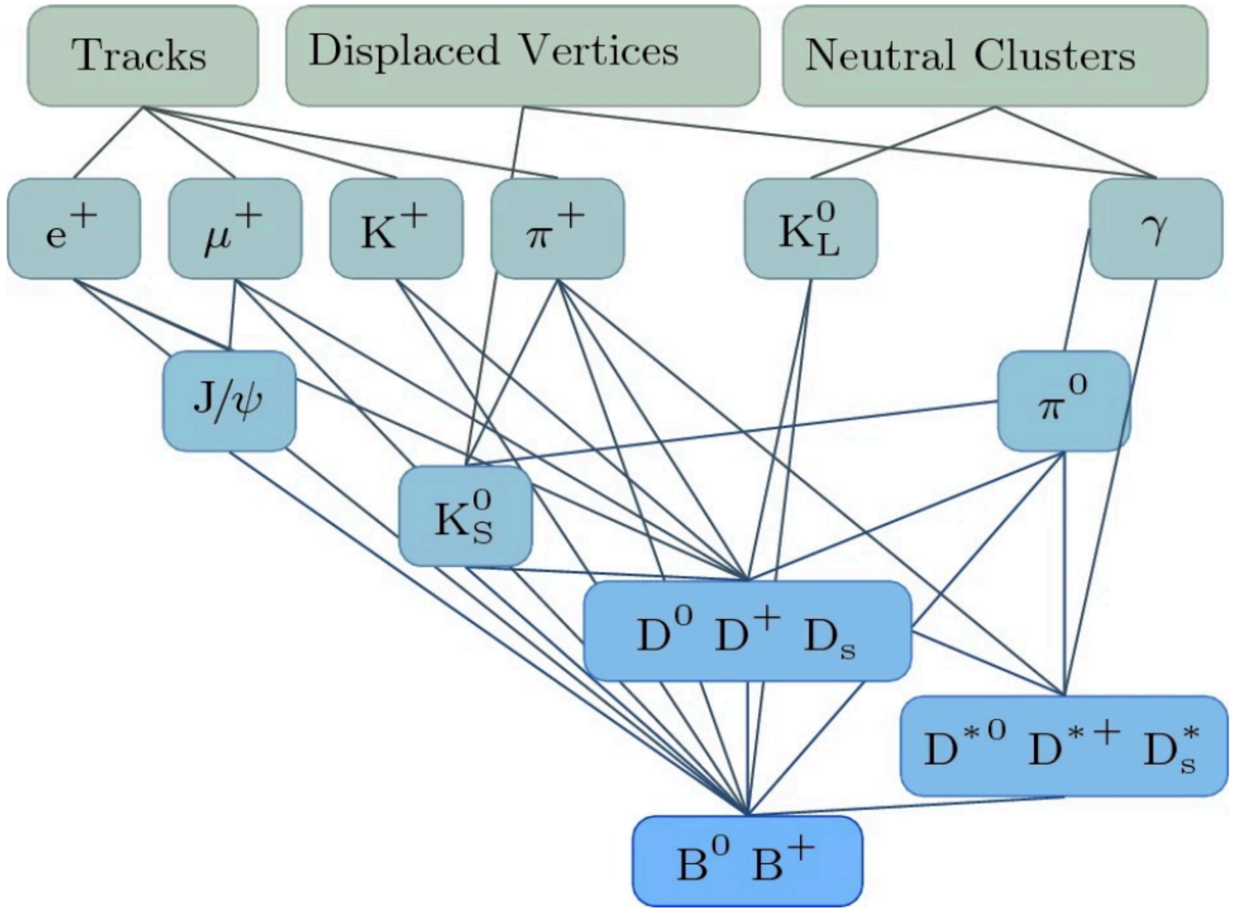
FEI

Full Event Interpretation

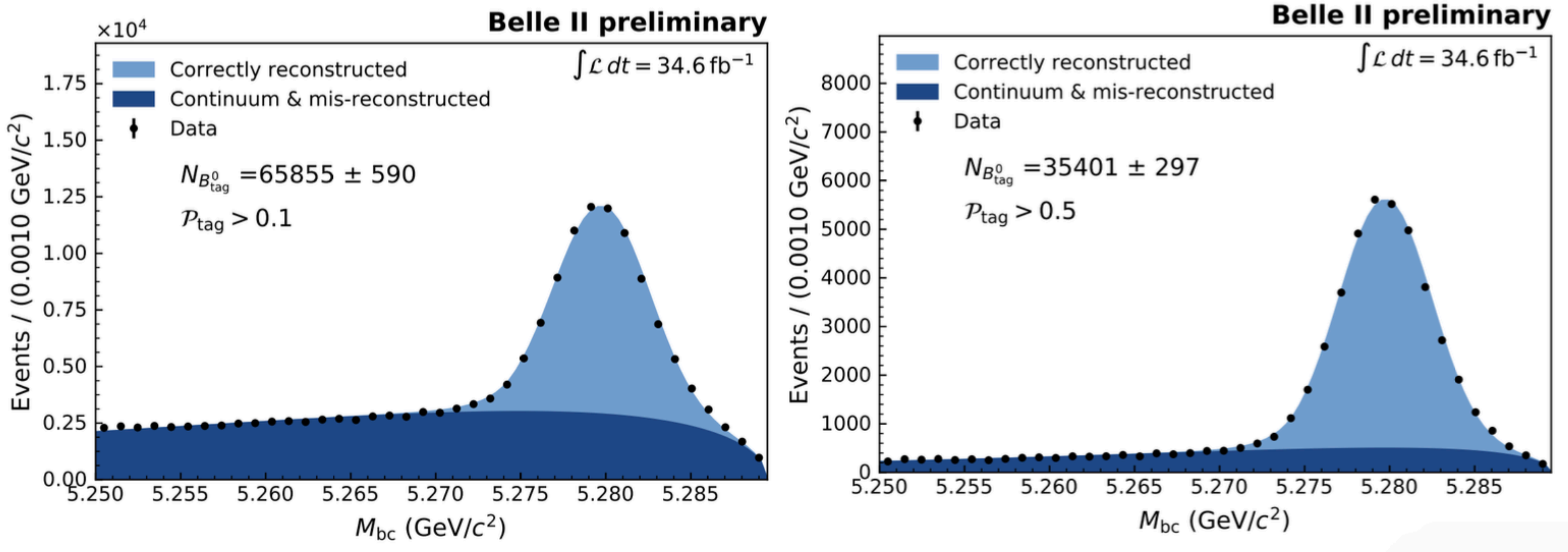
- FEI algorithm to reconstruct B_{tag}
  - uses ~200 BDT's to reconstruct $\mathcal{O}(10^4)$ different B decay chains
  - assign signal probability of being correct B_{tag}



Comput Softw Big Sci 3, 6 (2019)



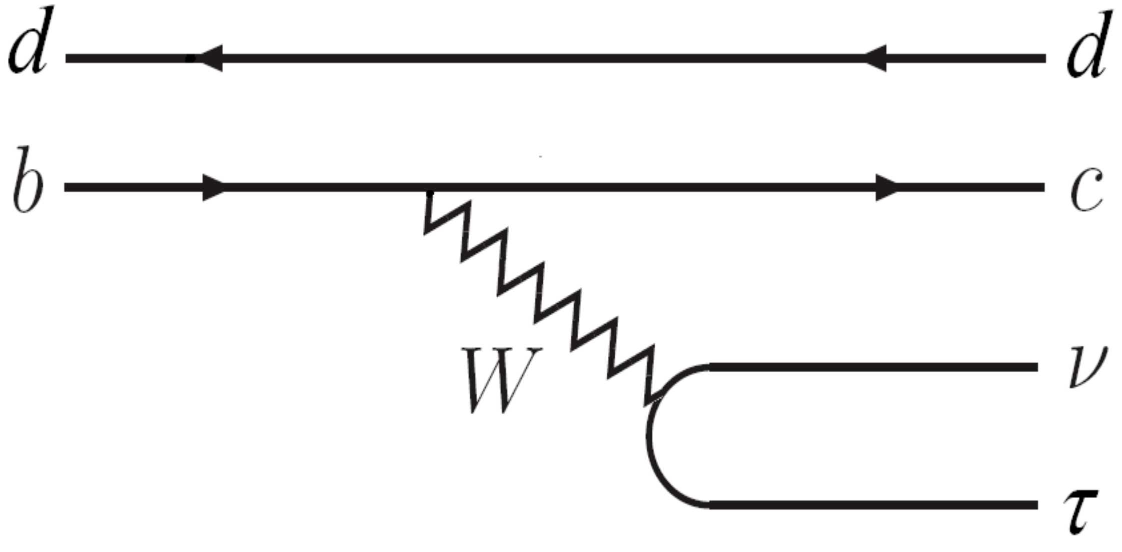
arXiv:2008.060965

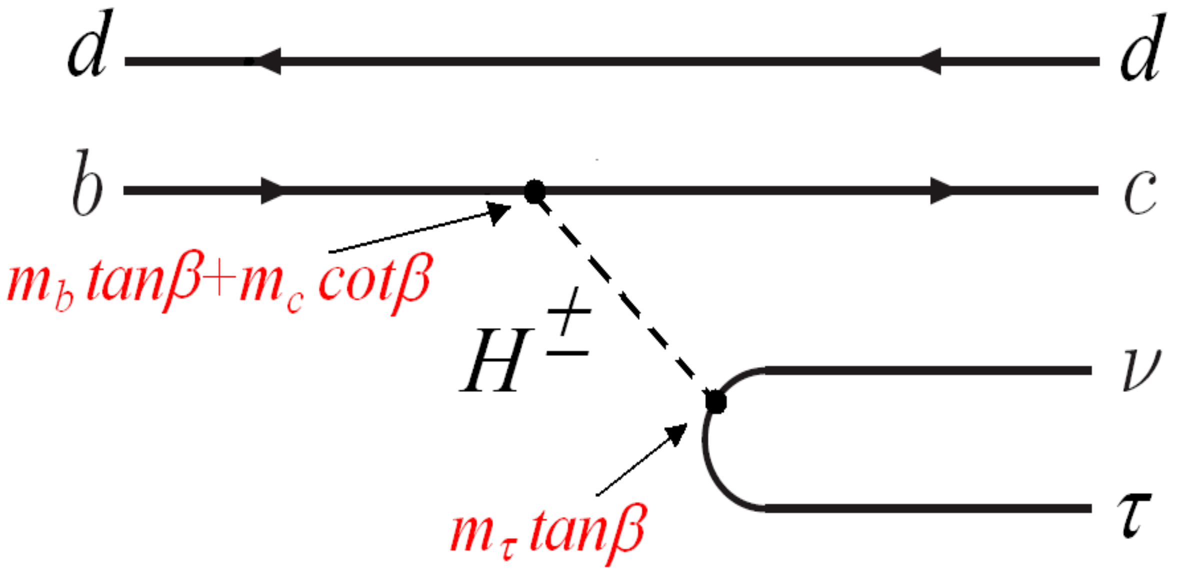


Some physics highlights

$B \to D^{(*)} \tau^+ \nu$

- good features
    - due to heavy m_τ, sensitive to H^+
    - $\mathcal{B}(B \to \overline{D}^{(*)} \tau^+ \nu) \gg \mathcal{B}(B^+ \to \tau^+ \nu)$
    - access to more dynamical info. through τ polarization
- but, very difficult for analysis
    - multiple ν's
    - large background from $B \to DX\ell^+ \nu$
- $B \to \overline{D}^{(*)} \tau^+ \nu$ depends on form-factor
    - but, it can be deduced from $B^+ \to \overline{D}^{(*)} \ell^+ \nu$





(SM) $\mathcal{B}(B \to \overline{D}^{*} \tau^+ \nu) \approx 1.4\%$, $\mathcal{B}(B \to \overline{D} \tau^+ \nu) \approx 0.7\%$

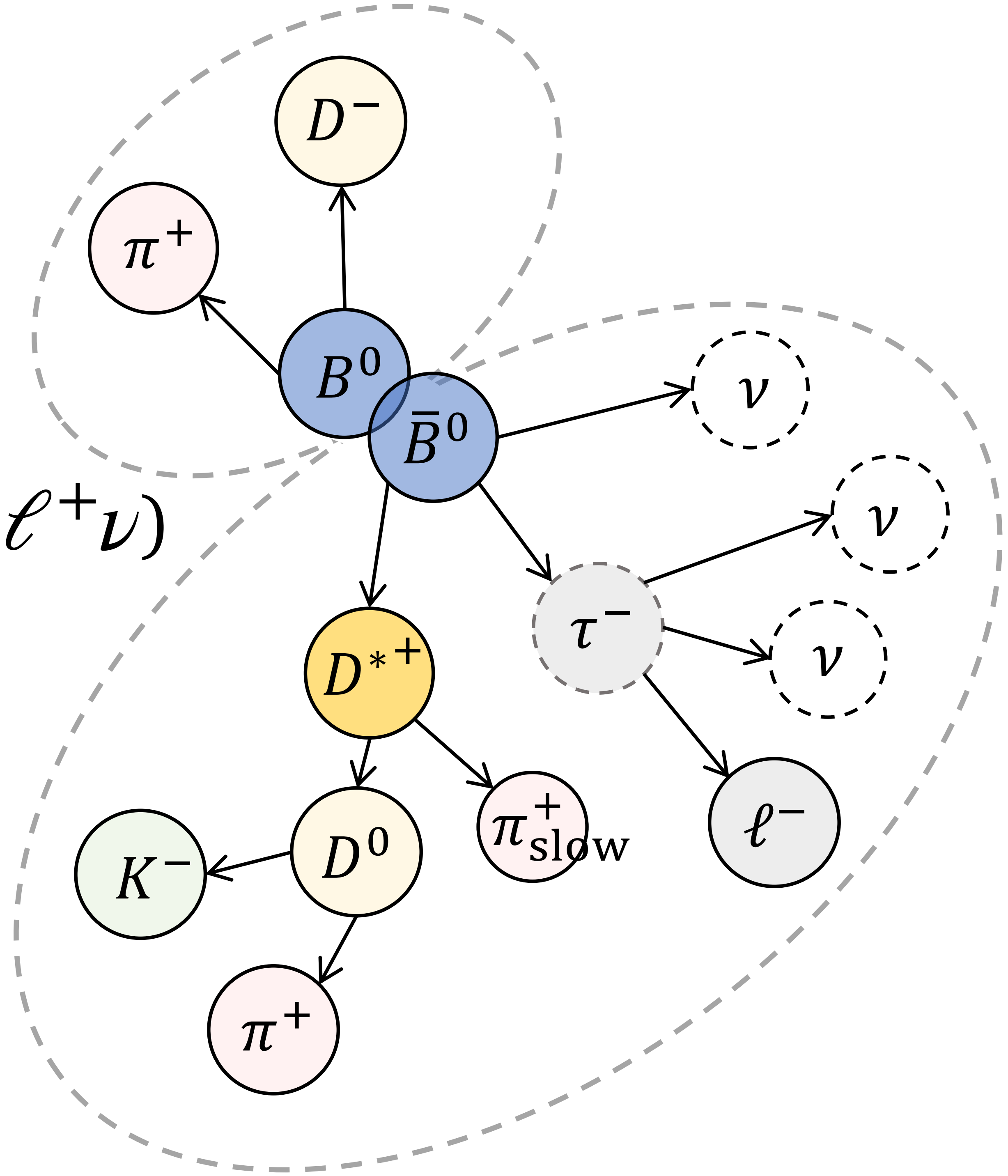
$R(D^*)$ from Belle II

$$R(D^*) \equiv \frac{\mathscr{B}(B \to D^*\tau^+\nu)}{\mathscr{B}(B \to D^*\ell^+\nu)}$$

- First $R(D^*)$ result from Belle II

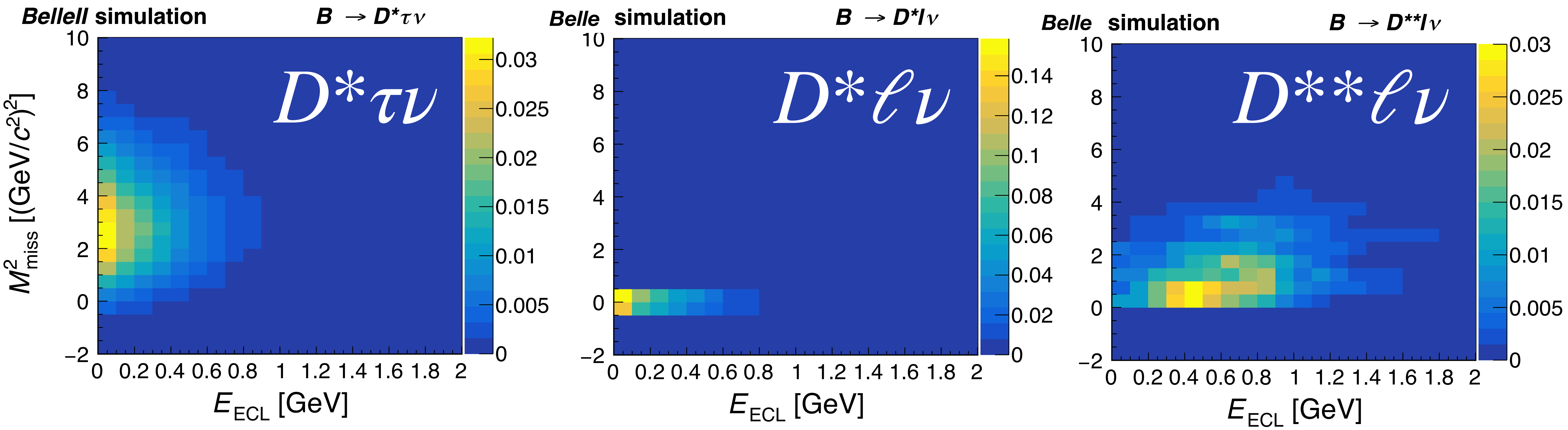
- Analysis features
  - Use hadronic B-tagging with FEI
  - leptonic τ decays, $\tau^+ \to \ell^+\nu_\ell\bar{\nu}_\tau$
  - three D^* modes: $D^{*+} \to D^0\pi^+$, $D^+\pi^0$ and $D^{*0} \to D^0\pi^0$

- Signal ($B \to D^*\tau^+\nu$) & Normalization ($B \to D^*\ell^+\nu$)
  - extracted simultaneously
  - by fitting 2D $(M^2_{\text{miss}}, E_{\text{ECL}})$



arXiv:2401.02840
PRD *accepted*

$R(D^*)$ from Belle II



- Signal ($B \to D^*\tau^+\nu$) & Normalization ($B \to D^*\ell^+\nu$)
  - extracted simultaneously
  - by fitting 2D $(M^2_{\rm miss}, E_{\rm ECL})$

$$M^2_{\rm miss} \equiv (p_{e^+e^-} - p_{B_{\rm tag}} - p_{D^*} - p_\ell)^2$$

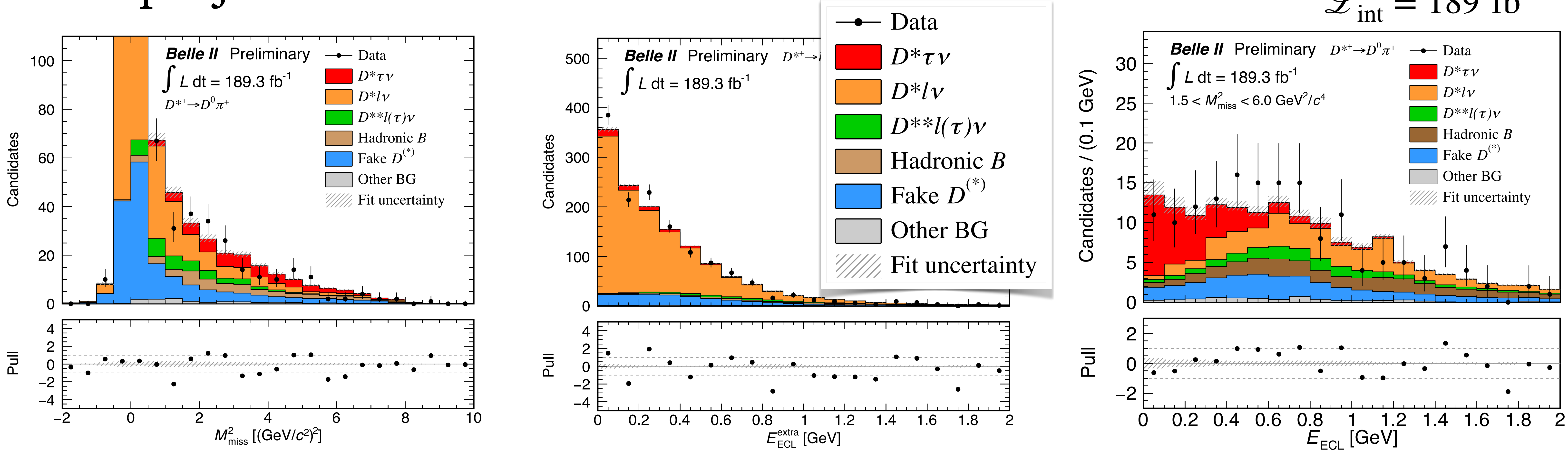
$E_{\rm ECL}$ = extra energy (unmatched) in the EM calorimeter

arXiv:2401.02840
PRD *accepted*

$R(D^*)$ from Belle II

- Fit projections for the sub-mode $D^{*+} \to D^0\pi^+$

$\mathscr{L}_{\text{int}} = 189\ \text{fb}^{-1}$



M^2_{miss} (peak-bin yield ~O(600))

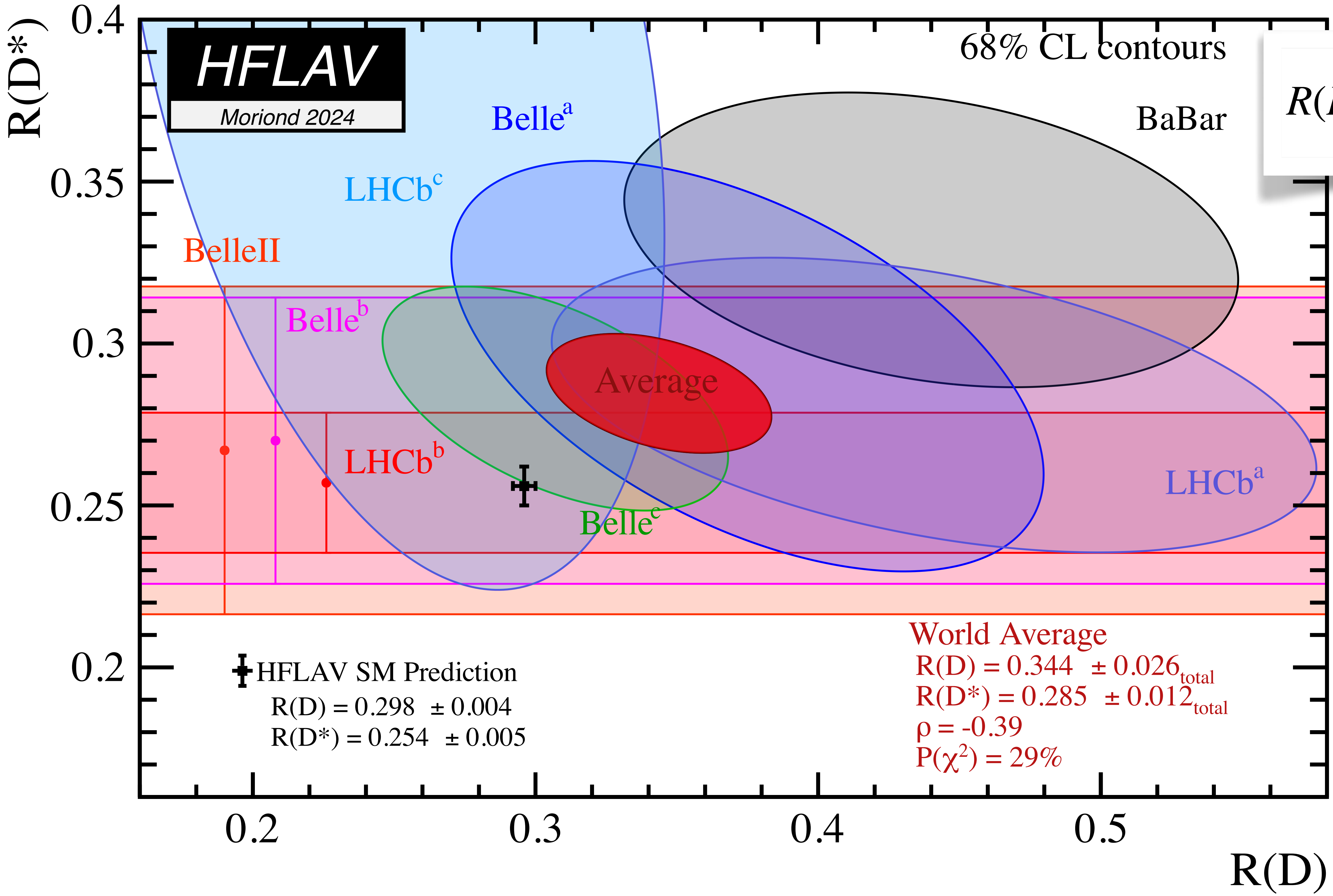
E_{ECL} for entire M^2_{miss} region

E_{ECL} for signal-enhanced region $1.5 < M^2_{\text{miss}} < 6.0\ \text{GeV}^2$

$$R(D^*) = 0.262^{+0.041}_{-0.039}{}^{+0.035}_{-0.032}$$

- Systematics
  - dominant sources: E_{ECL} PDF shape, MC statistics

LFU test via $R(D)$ vs. $R(D^*)$



$$R(D^*) \equiv \frac{\mathscr{B}(B \to D^*\tau^+\nu)}{\mathscr{B}(B \to D^*\ell^+\nu)}$$

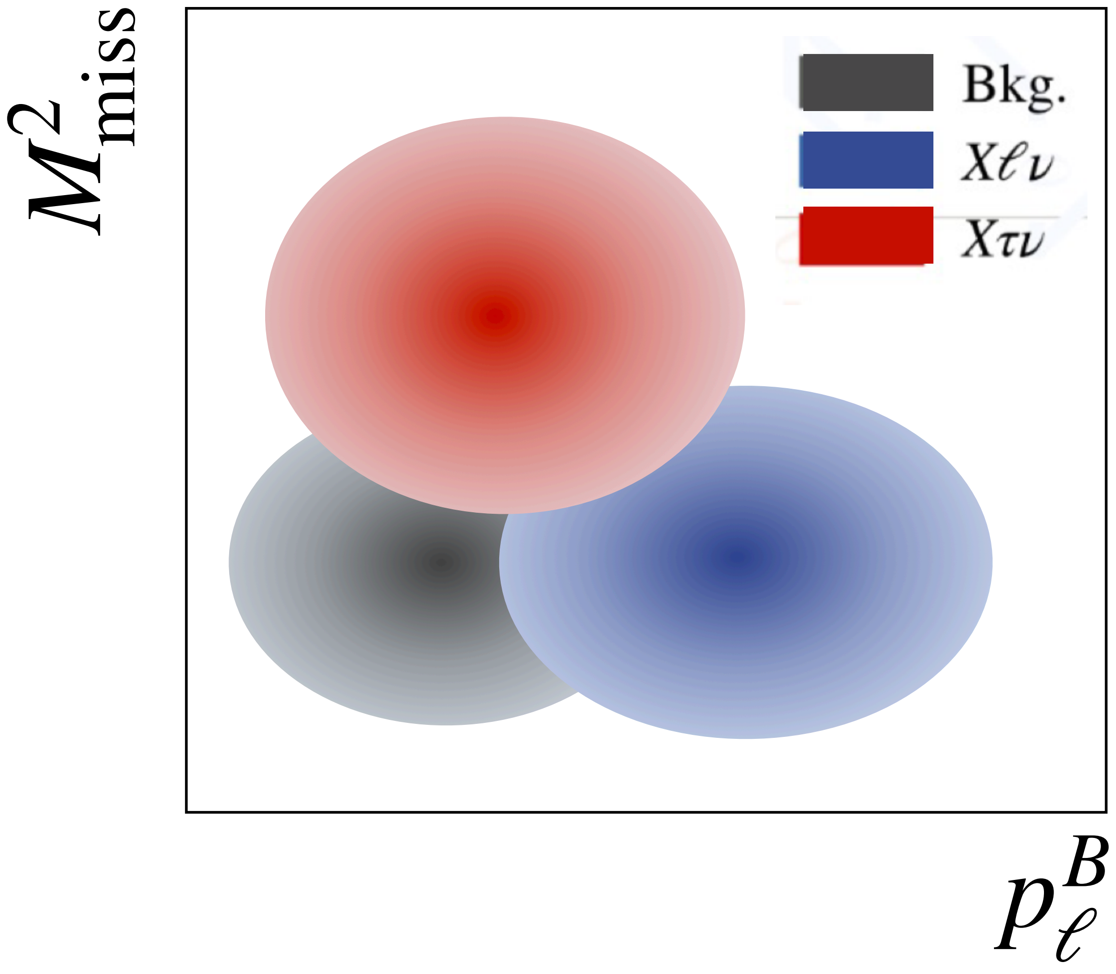
WA is 3.17σ from SM.

Inclusive LFU test w/ $R(X_{\tau/\ell})$

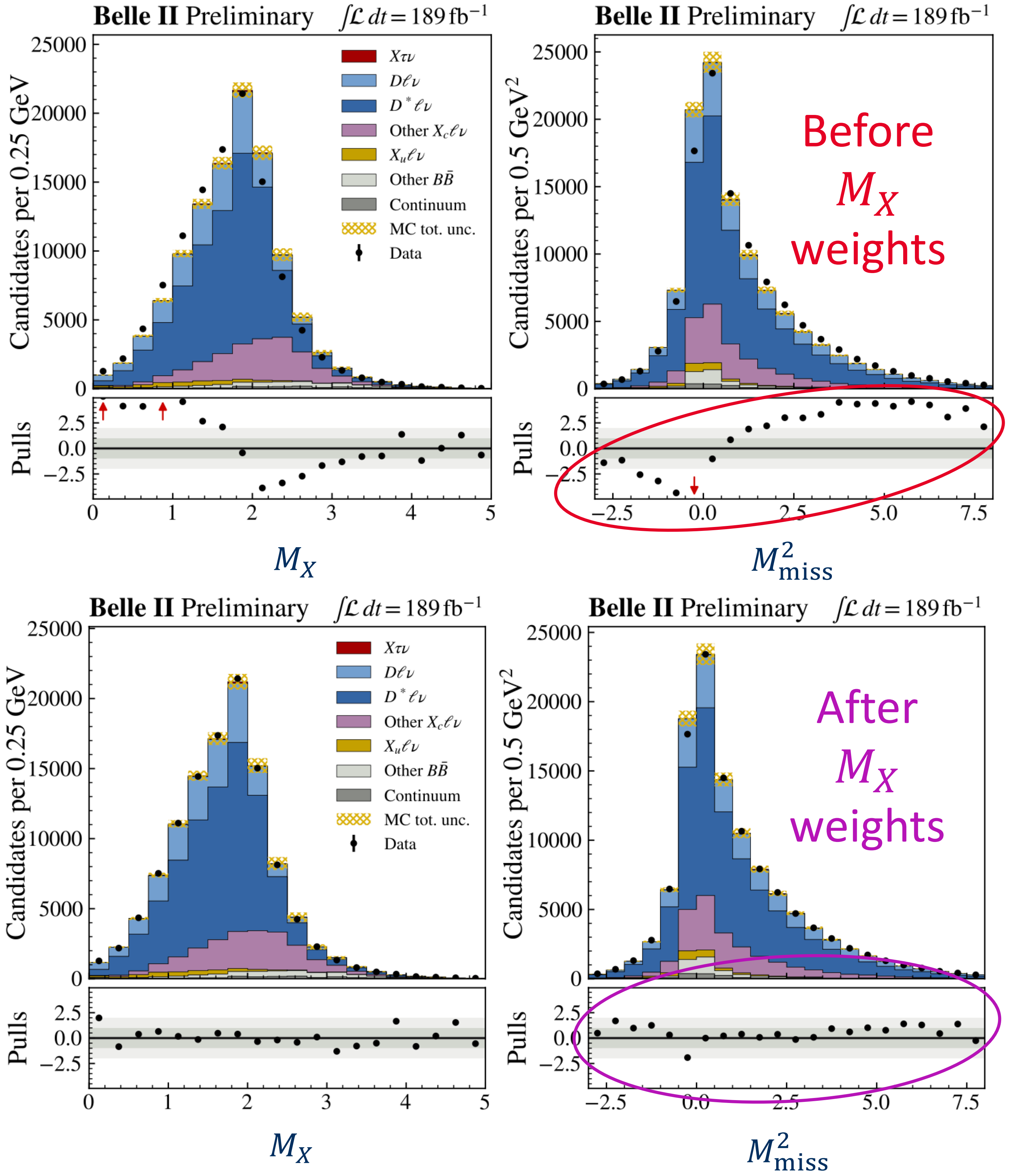
- Why measure $R(X_{\tau/\ell})$?
  - different systematics from $R(D^{(*)})$
  - hence, a complementary test of LFU

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

- Procedure
  - use $\tau \to \ell\nu_\tau\bar{\nu}_\ell$ modes
  - select events with $B_{\text{tag}} + \ell$, with remaining particles attributed to X
  - distinguish signal from background by using M^2_{miss} and p^B_ℓ
  - background mostly from $b \to c \to \ell$; some continuum and fake leptons



$R(X_{\tau/\ell})$, event distributions



- for reliable template shapes for fitting
  - make detailed adjustments to MC (FF's, B and D BF's)
  - corrections by comparing MC to data in control region: low q^2, low M^2_{miss}, high M_X
  - e.g. adjust M_X in p_ℓ > 1.4 GeV sideband; using these weights also improves modeling in M^2_{miss} and q^2

Main sources of systematic uncertainty:

MC stat	± 5.7 %
Bkg shape	± 5.5 %
M_X modeling	± 7.1 %
$B \to X_c \ell \nu$ BFs	± 7.7 %
$B \to X_c \ell \nu$ FFs	± 7.9 %

Phys. Rev. Lett. 132, 211804 (2024)

$R(X_{\tau/\ell})$ Results

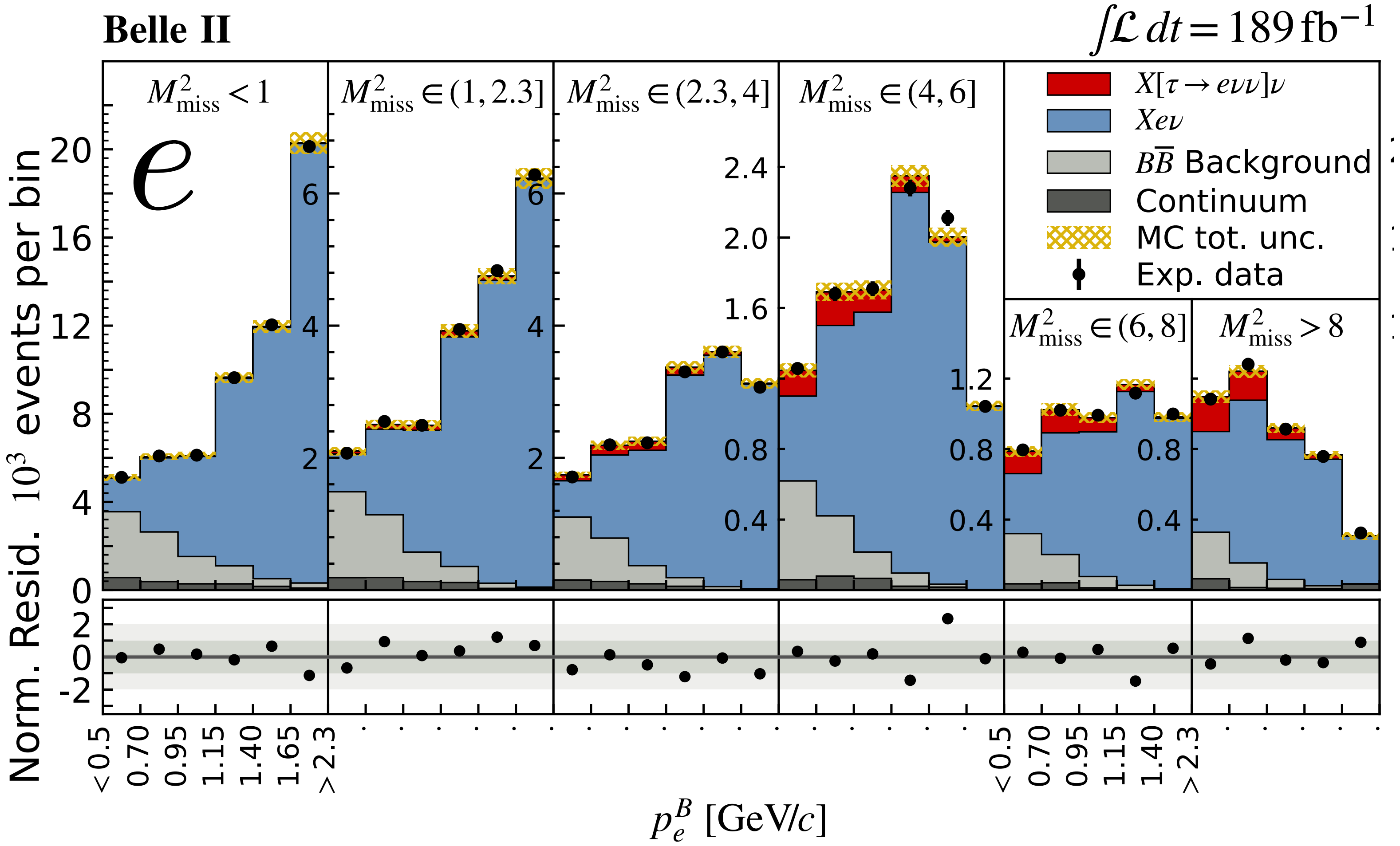
$$R(X_{\tau/\ell}) = 0.228 \pm 0.016 \pm 0.036$$

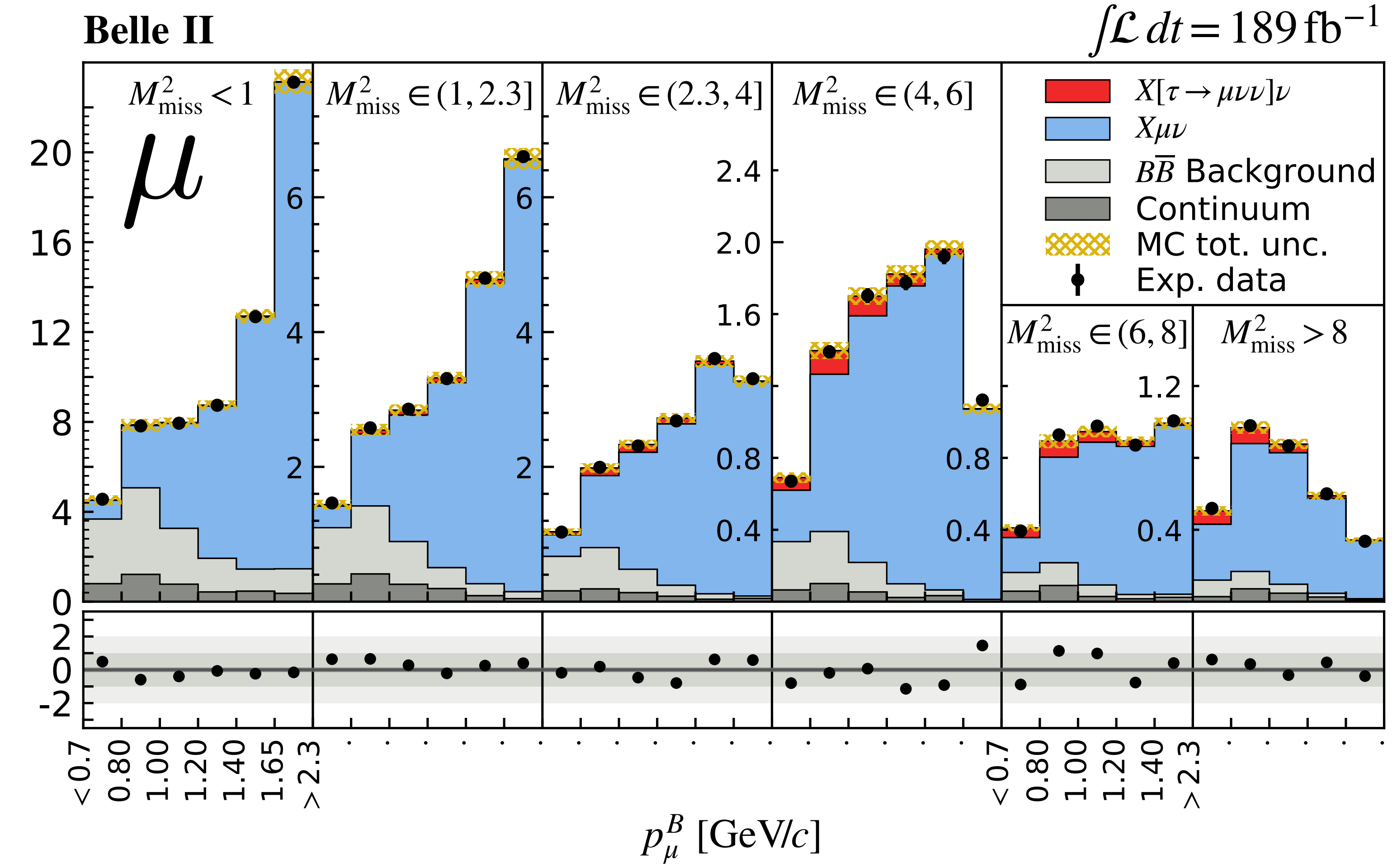
$$R(X_{\tau/e}) = 0.232 \pm 0.020 \pm 0.037$$

$$R(X_{\tau/\mu}) = 0.222 \pm 0.027 \pm 0.050$$

Consistent with SM: 0.223 ± 0.005

M. Freytsis et al. PRD 92, 054018 (2015)
M. Rahimi, K. K. Vos, JHEP 2022, 7 (2022)
Z. Ligeti et al. PRD 105, 073009 (2022)

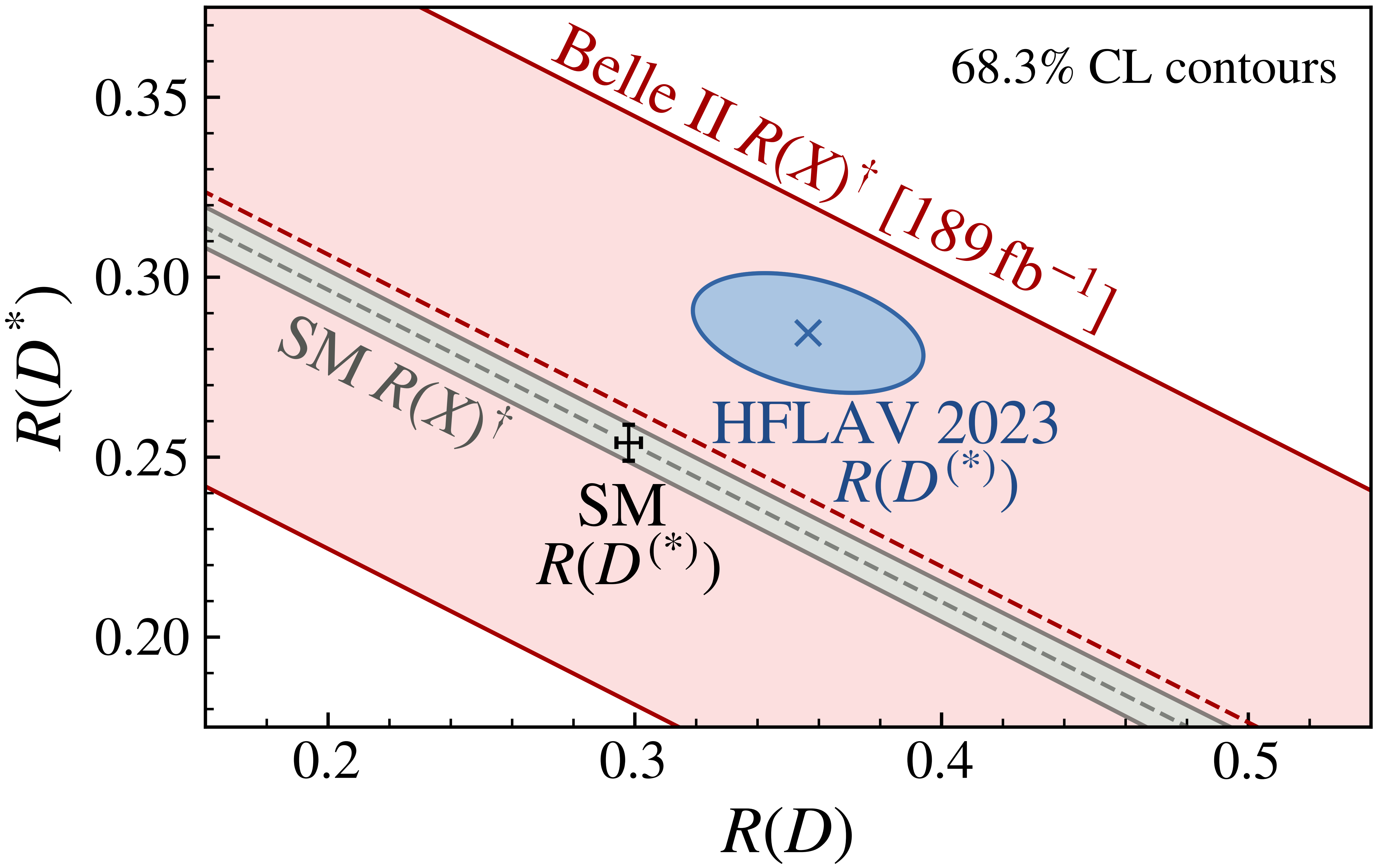


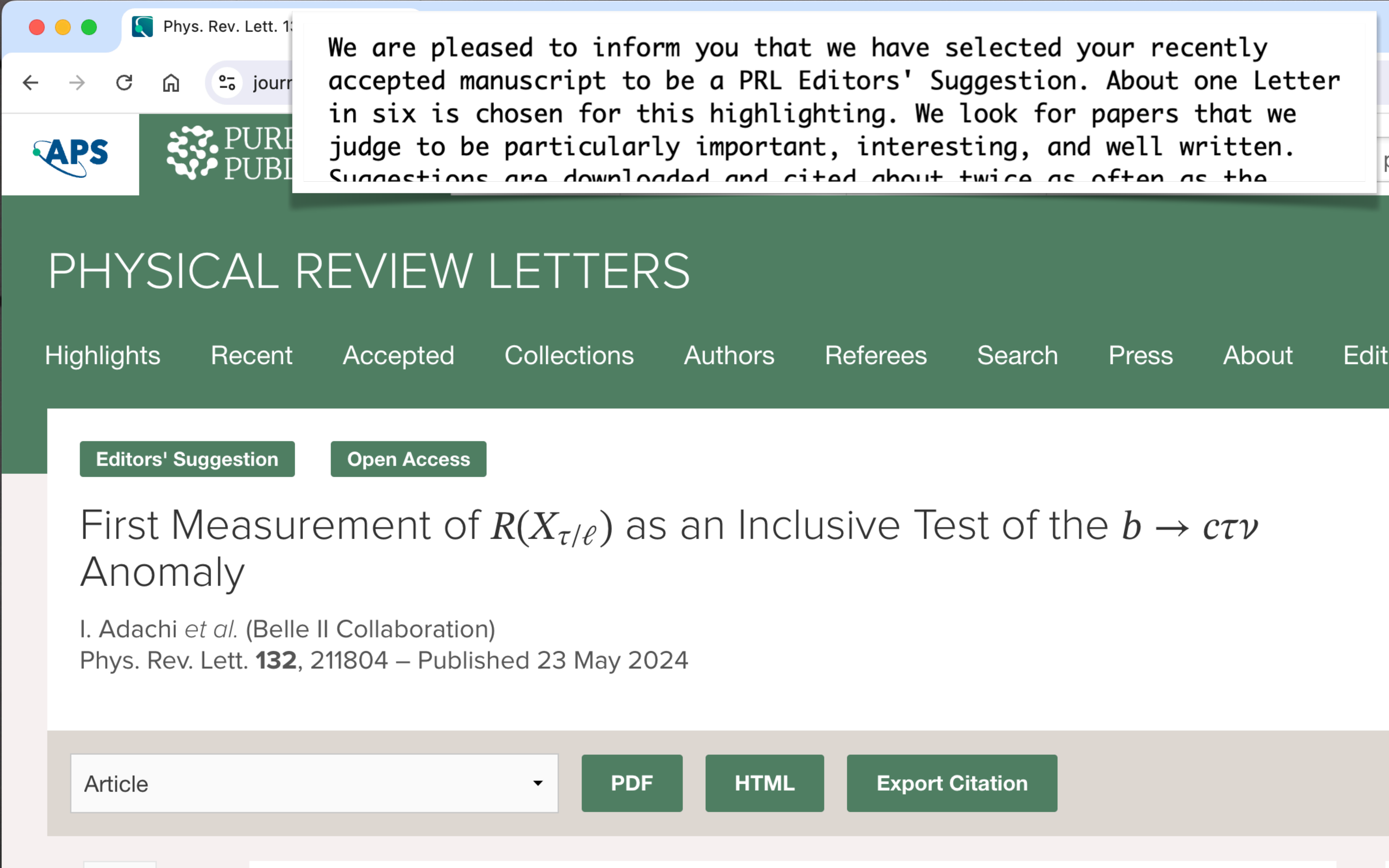


Phys. Rev. Lett. 132, 211804 (2024)

$R(X_{\tau/\ell})$, compared with $R(D^{(*)})$

† = with expected SM contributions of $D^{**}_{\text{(gap)}}, X_u$ removed





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judge to be particularly important, interesting, and well written.
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PHYSICAL REVIEW LETTERS

Editors' Suggestion **Open Access**

First Measurement of $R(X_{\tau/\ell})$ as an Inclusive Test of the $b \to c\tau\nu$ Anomaly

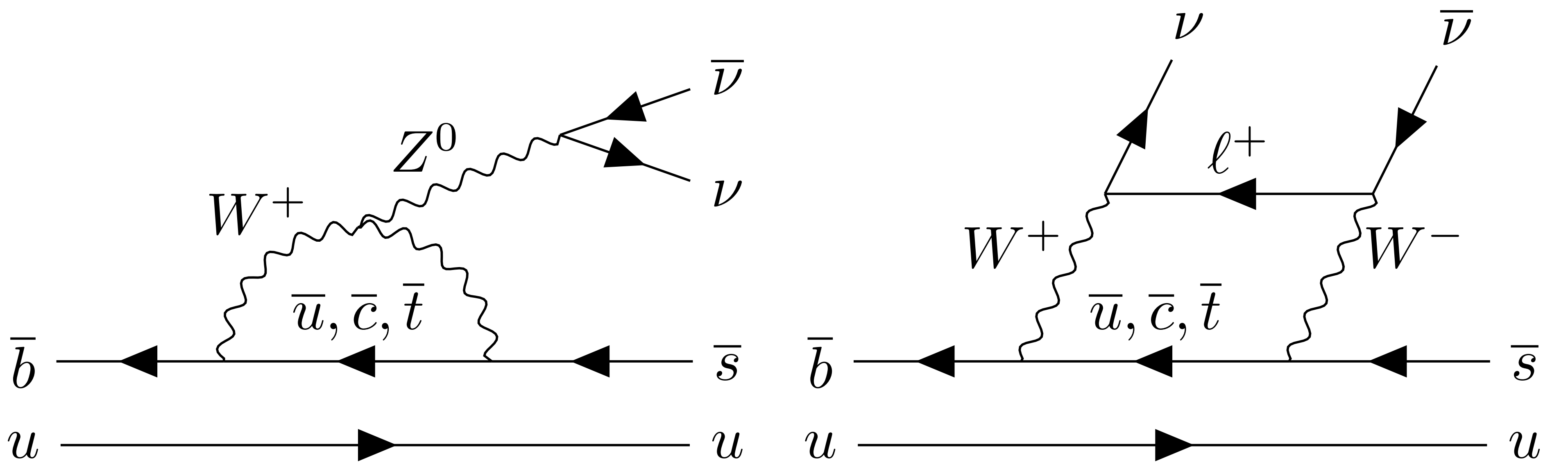
I. Adachi *et al.* (Belle II Collaboration)

Phys. Rev. Lett. **132**, 211804 – Published 23 May 2024

Search for $B^+ \to K^+\nu\bar{\nu}$ at Belle II

- In the SM,
  - $\mathscr{B}(B^+ \to K^+\nu\bar{\nu}) = (5.58 \pm 0.37) \times 10^{-6}$ [4]
- sensitive to new physics BSM, e.g.
  - leptoquarks,
  - axions,
  - DM particles, etc.

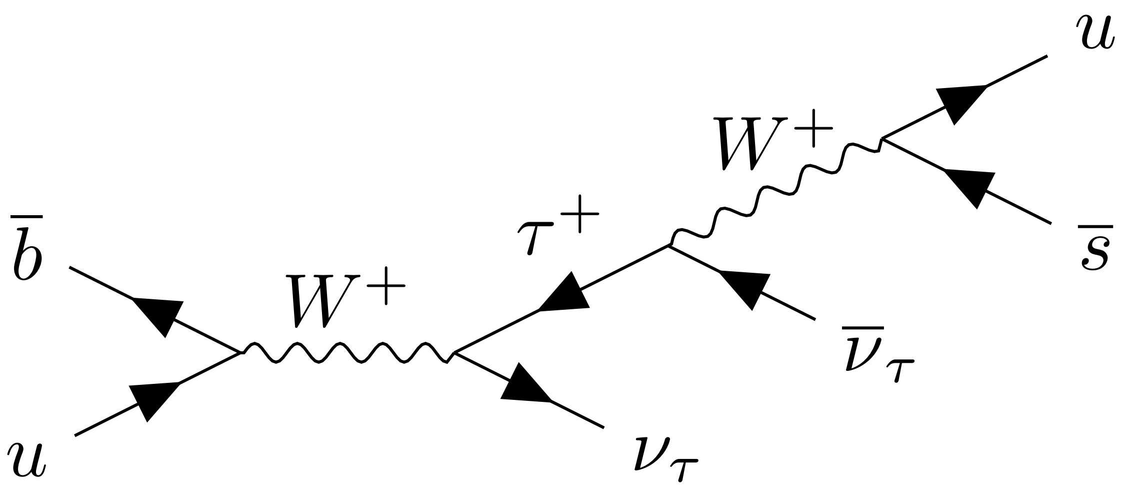
[4] W. G. Parrott et al. PRD 107, 014511 (2023)
incl. long-distance contribution from $B \to \tau\nu$)



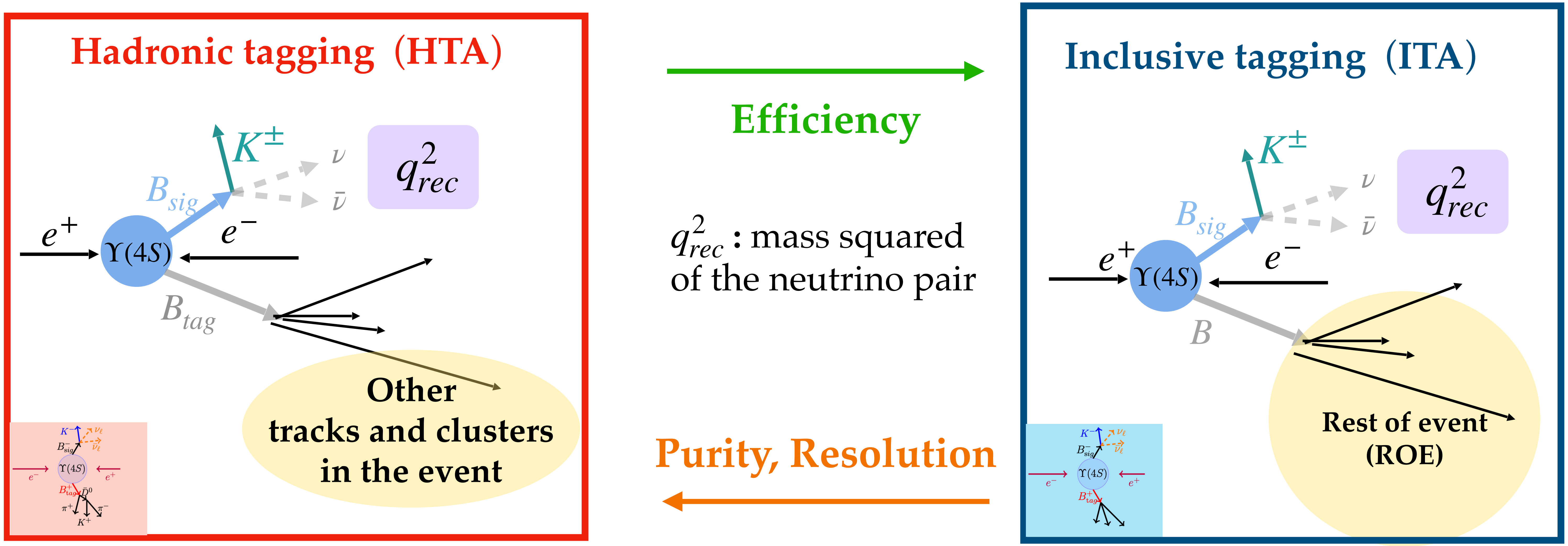
PRL 127, 181802 (2021)

$$\mathcal{B}(B^+ \to K^+\nu\bar{\nu}) = (1.9^{+1.3+0.8}_{-1.3-0.7}) \times 10^{-5}$$

$$< 4.1 \times 10^{-5}$$ @ 90% CL



Two ways of tagging



Hadronic tagging (HTA)

Other tracks and clusters in the event

Efficiency

q^2_{rec} : mass squared of the neutrino pair

Purity, Resolution

Inclusive tagging (ITA)

Rest of event (ROE)

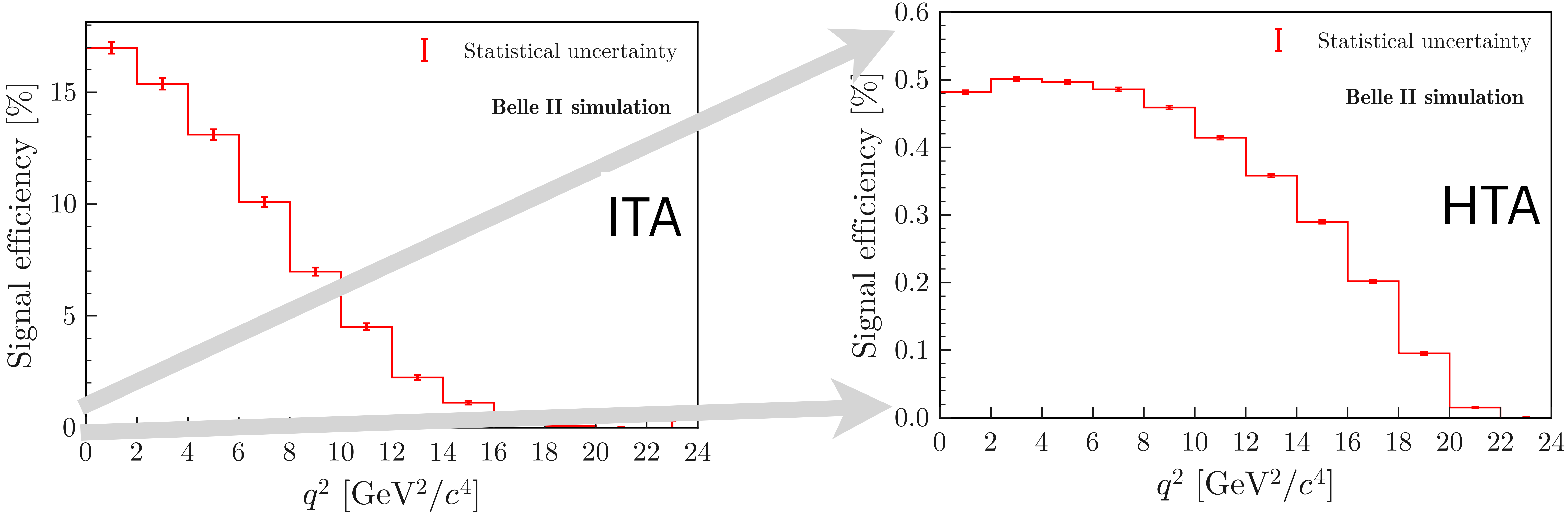
- Features of HTA
  - uses full decay chain information of of B_{tag}
  - high high purity, very low efficiency
  - uses BDT for signal extraction ($\mathrm{BDT_h}$)
- Features of ITA
  - exploits inclusive properties of B_{tag}
  - high efficiency, low purity
  - BDTs in two stages ($\mathrm{BDT_1}$ mostly for $q\bar{q}$; $\mathrm{BDT_2}$ for final signal extraction)

Phys. Rev. D. 109, 112006 (2024)

Signal efficiency (ITA vs. HTA)

after multi-variate analysis for ROE with BDT

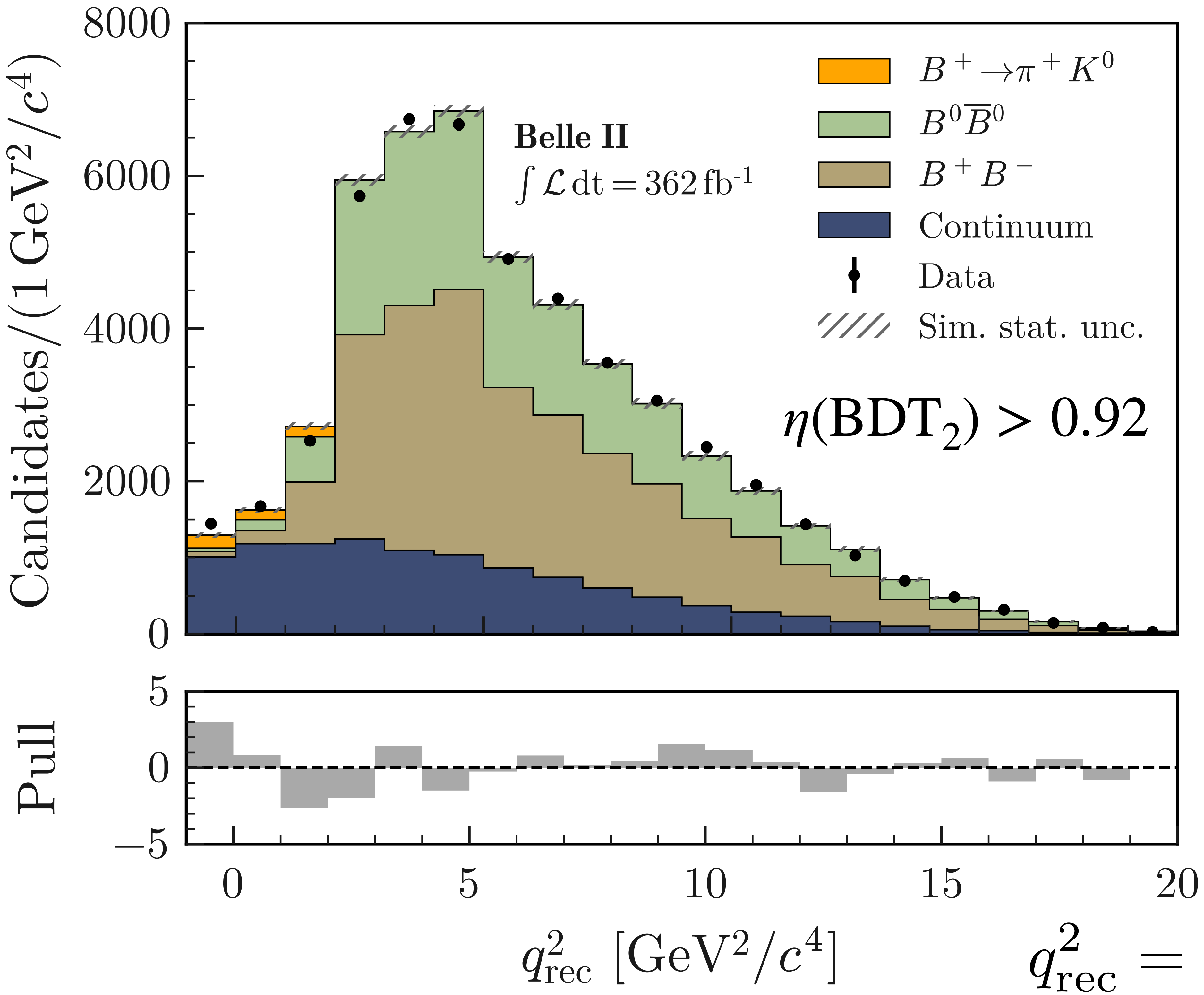
for BDT efficiency validation, see p. 42 in the Appendix



$$q^2 = M(\nu\bar{\nu})^2$$

Phys. Rev. D. 109, 112006 (2024)

Closure test (ITA)



- Pion ID instead of kaon ID
- Different q^2_{rec} bin boundaries
- Only on-resonance data used for fit
- Only normalization systematics included

Result:

- $\mathscr{B}(B^+ \to \pi^+ K^0) = (2.5 \pm 0.5) \times 10^{-5}$

Consistent with PDG:

$\mathscr{B}(B^+ \to \pi^+ K^0) = (2.3 \pm 0.08) \times 10^{-5}$

$$q^2_{\mathrm{rec}} = s/4 + M^2_{\pi^+} - \sqrt{s}E^*_{\pi^+}$$

Assume B is at rest in the $\Upsilon(4S)$ rest-frame ($c = 1$)

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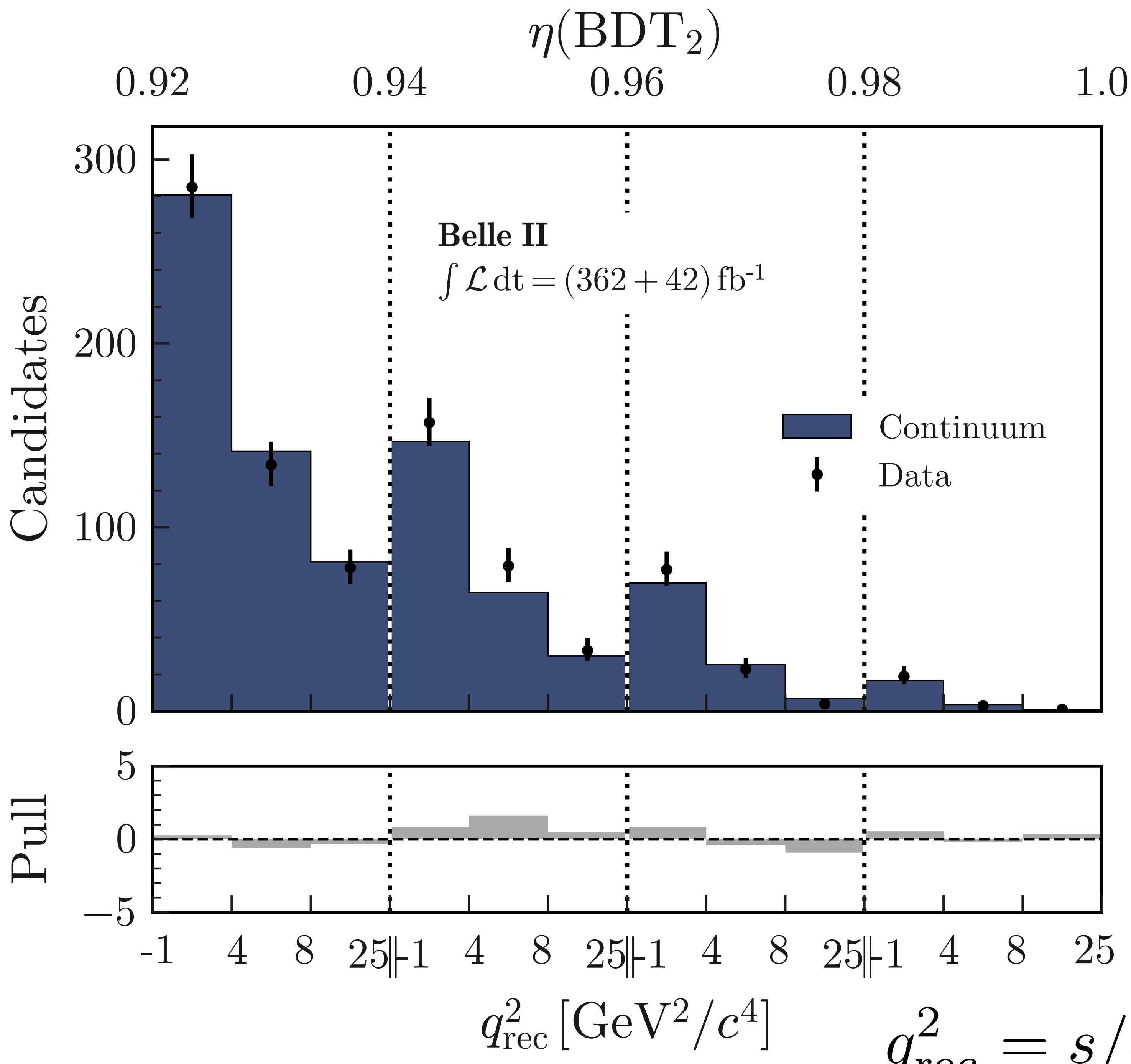
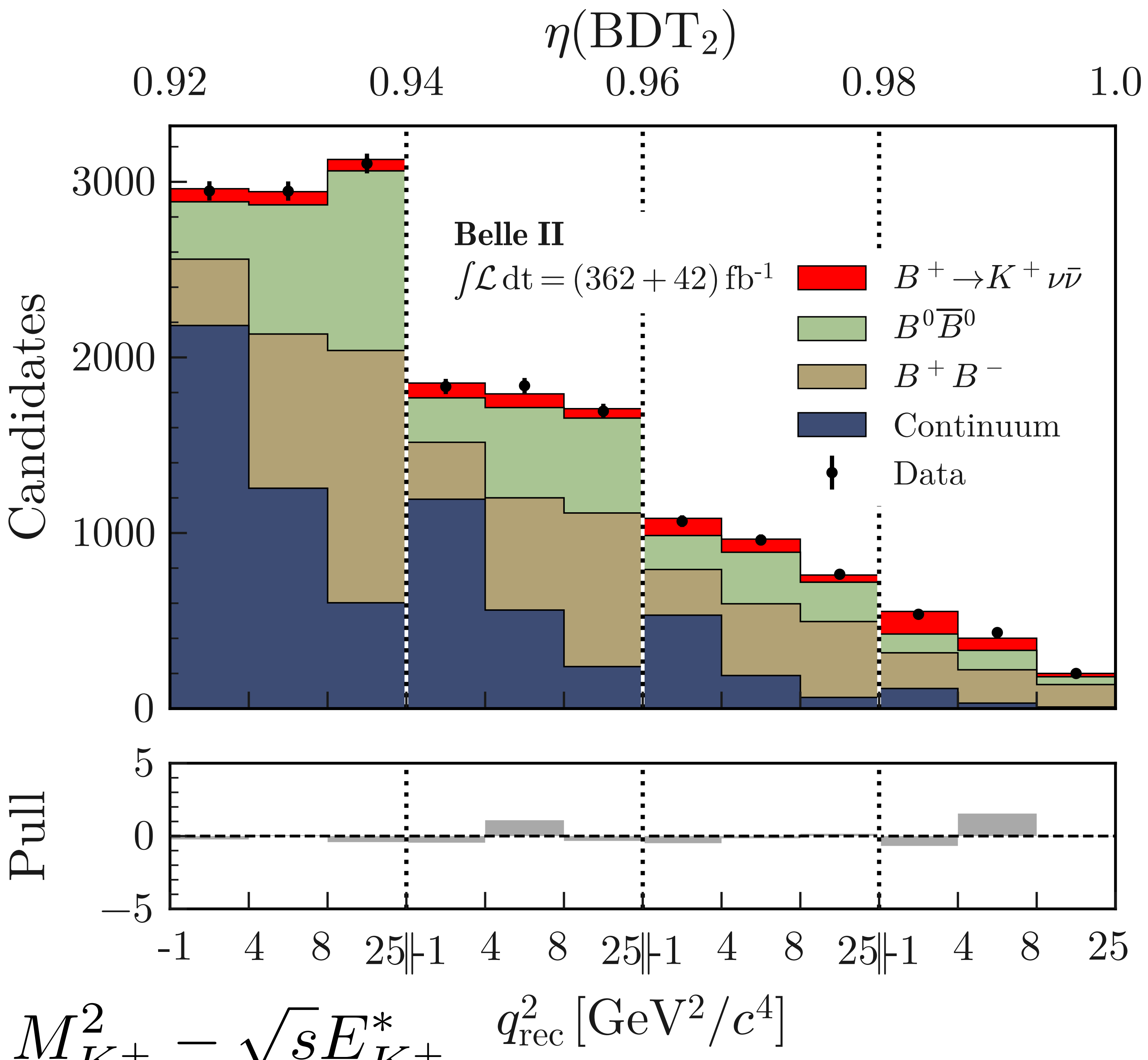
$B^+ \to K^+\nu\bar{\nu}$ result (ITA)



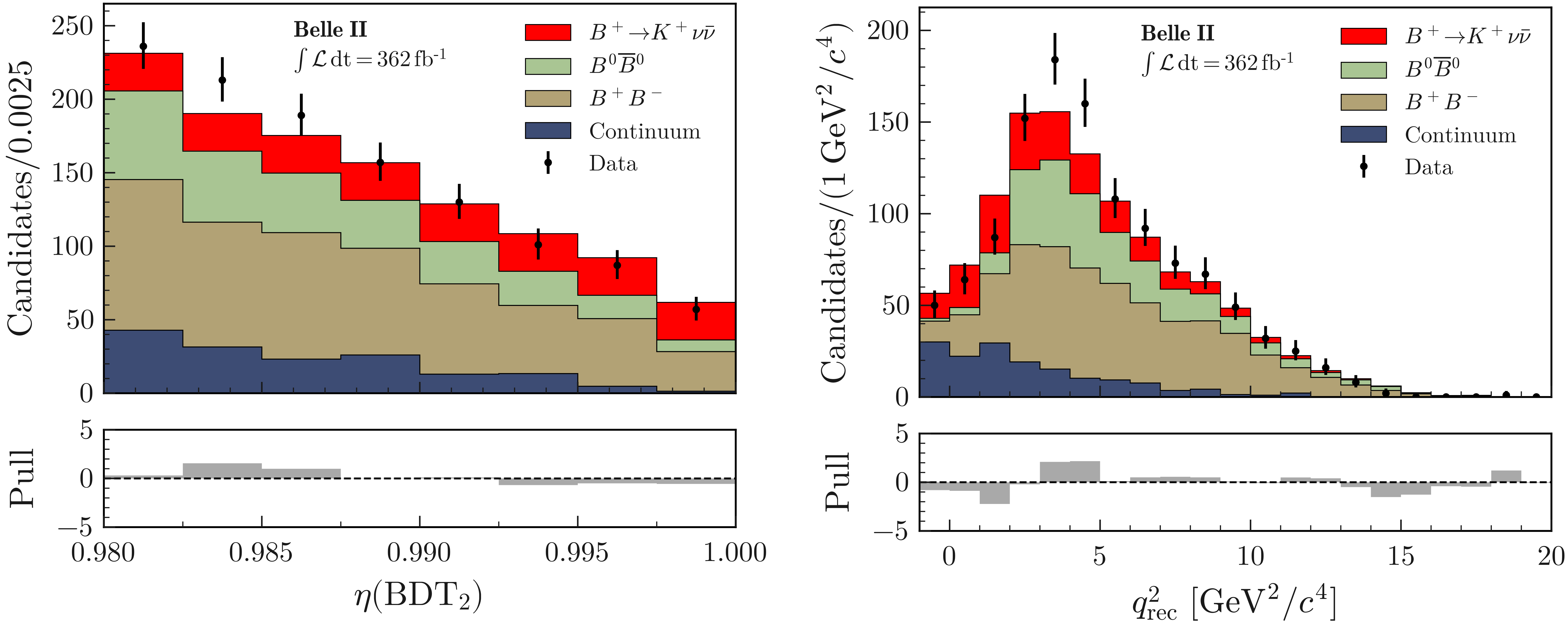


$$q^2_{\mathrm{rec}} = s/4 + M^2_{K^+} - \sqrt{s}E^*_{K^+}$$

$$\mathscr{B}(B^+ \to K^+\nu\bar{\nu})_{\mathrm{ITA}} = (2.7 \pm 0.5 \pm 0.5) \times 10^{-5}$$

$B^+ \to K^+\nu\bar{\nu}$ post-fit distributions (ITA)

$$\eta(\mathrm{BDT}_2) > 0.98$$



$$q^2_{\mathrm{rec}} = s/4 + M^2_{K^+} - \sqrt{s}E^*_{K^+}$$

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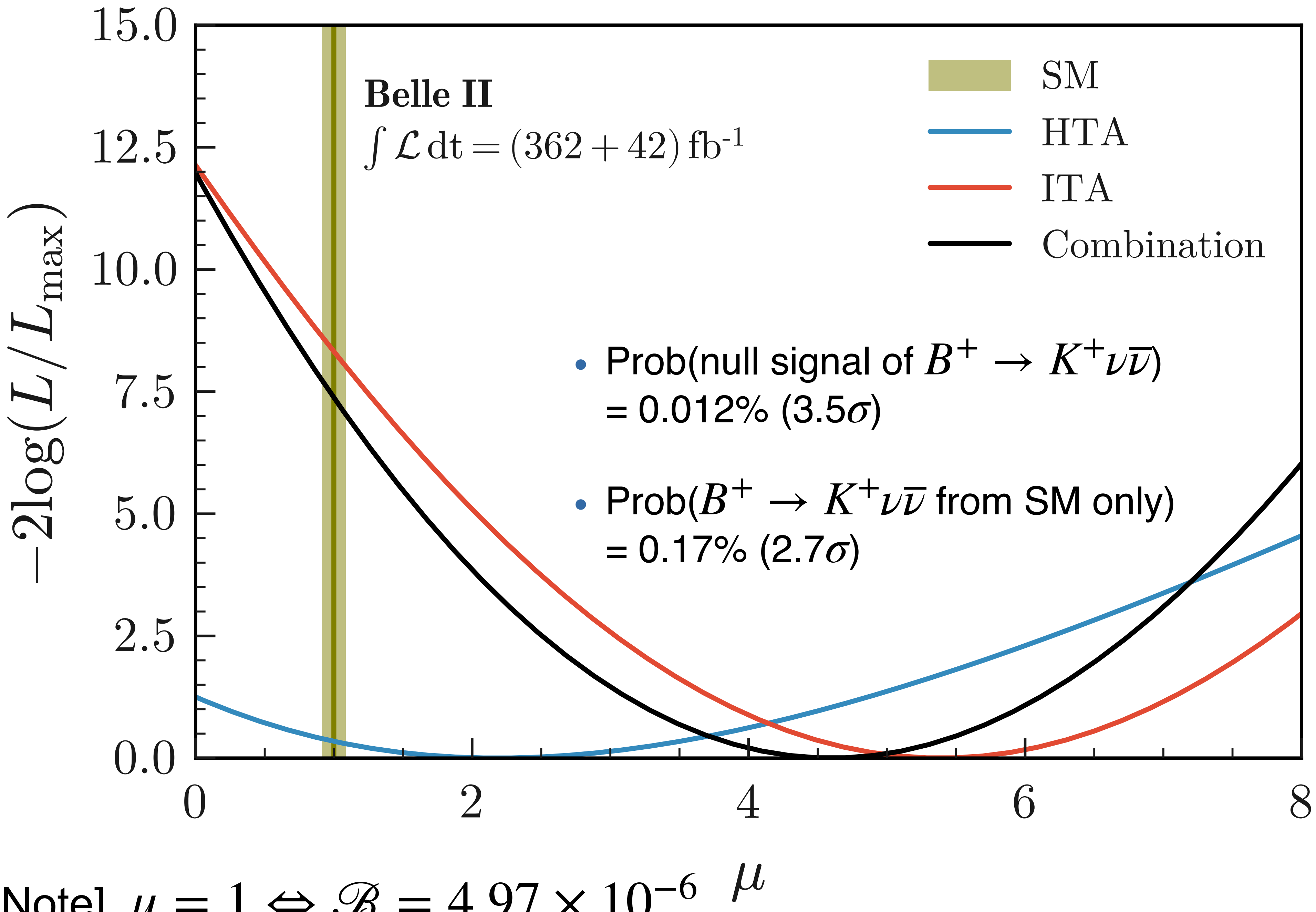
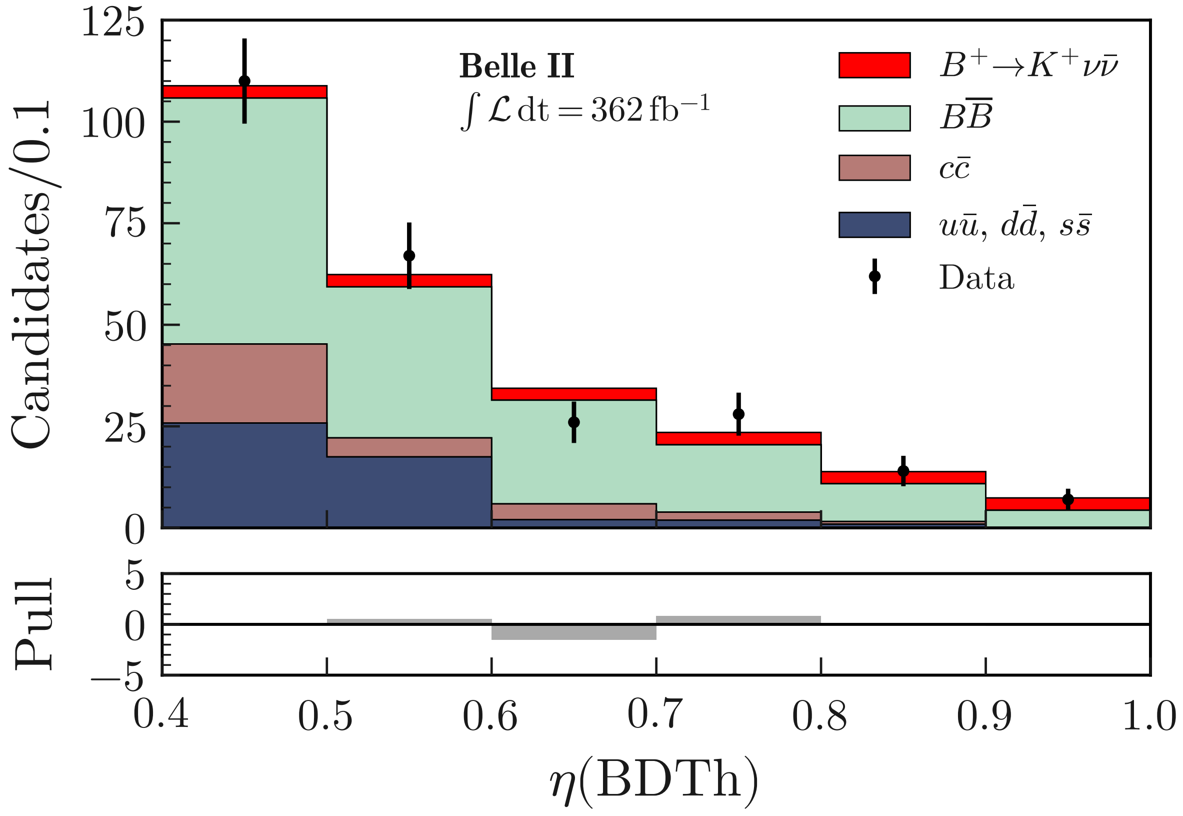
112006 (2024)

$B^+ \to K^+\nu\bar{\nu}$
(combined)



- Prob(null signal of $B^+ \to K^+\nu\bar{\nu}$) = 0.012% (3.5σ)
- Prob($B^+ \to K^+\nu\bar{\nu}$ from SM only) = 0.17% (2.7σ)

[Note] $\mu = 1 \Leftrightarrow \mathscr{B} = 4.97 \times 10^{-6}$
(SM value not incl. $B \to \tau\nu$)



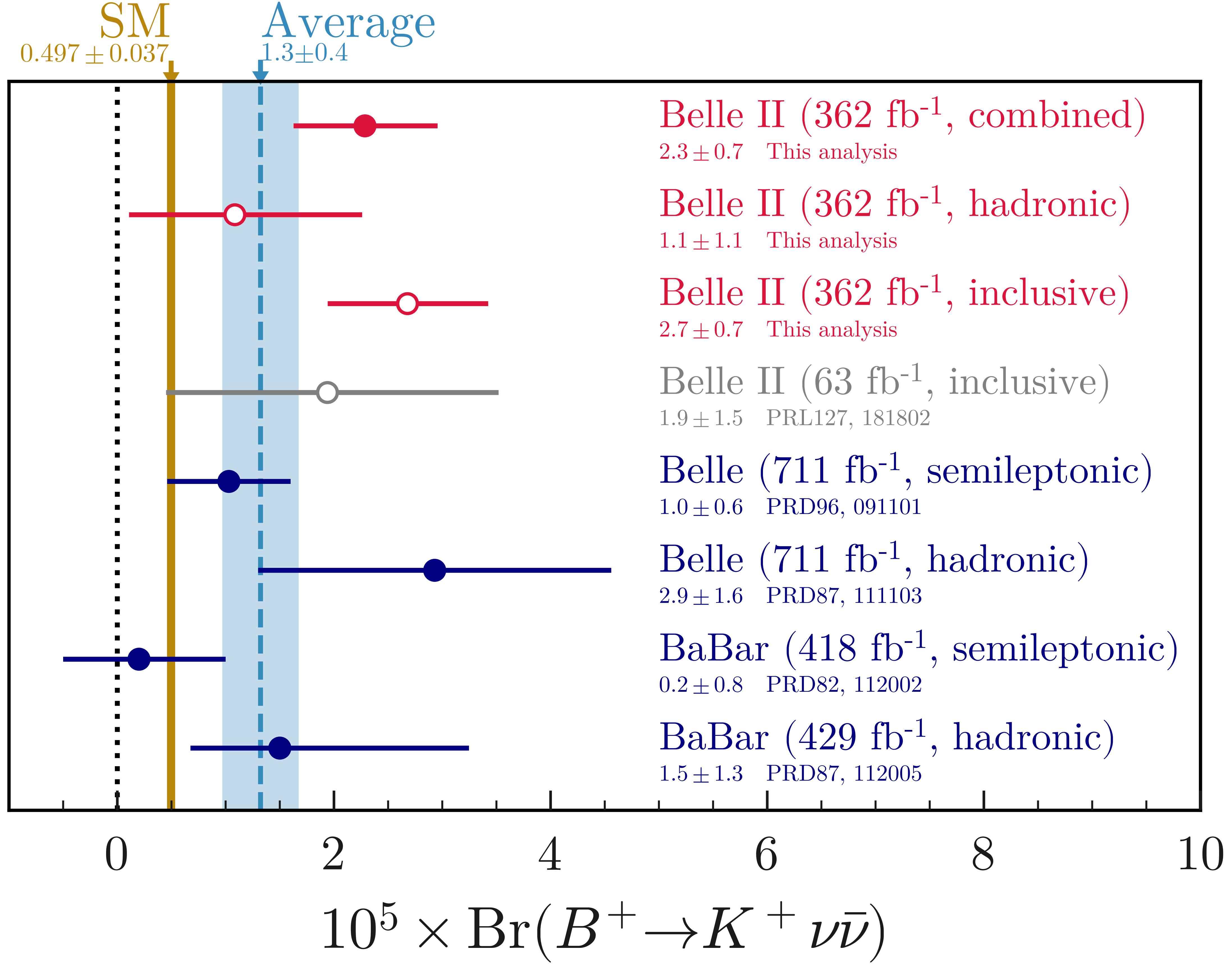
$$\mathscr{B}(B^+ \to K^+\nu\bar{\nu})_{\mathrm{HTA}} = (1.1^{+0.9+0.8}_{-0.8-0.5}) \times 10^{-5}$$

$$\mathscr{B}(B^+ \to K^+\nu\bar{\nu})_{\mathrm{ITA}} = (2.7 \pm 0.5 \pm 0.5) \times 10^{-5}$$

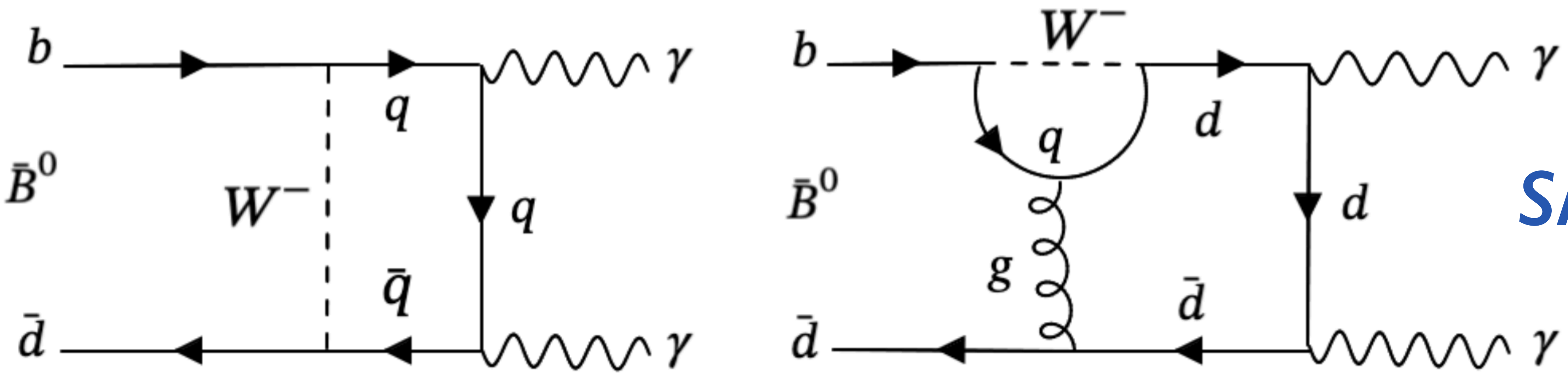
$$\mathscr{B}(B^+ \to K^+\nu\bar{\nu})_{\mathrm{comb}} = (2.3 \pm 0.5^{+0.5}_{-0.4}) \times 10^{-5}$$

Phys. Rev. D. 109, 112006 (2024)

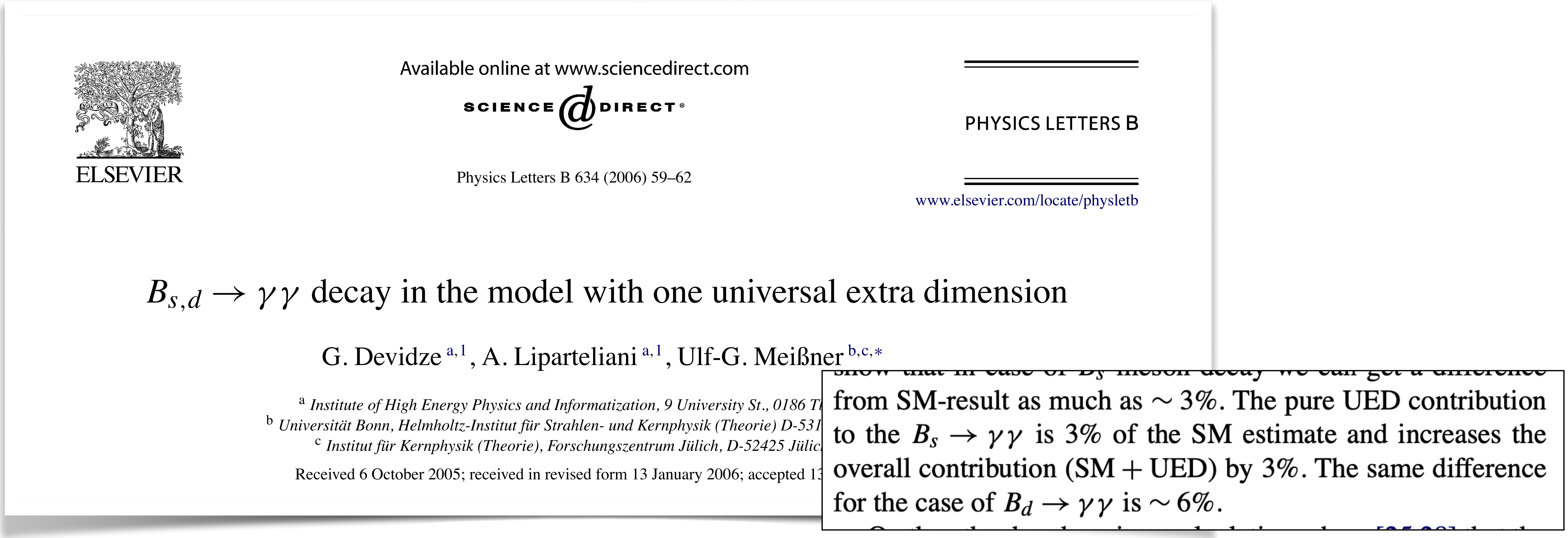
$\mathscr{B}(B^+ \to K^+\nu\bar{\nu})$ global picture



$B^0_{(s)} \to \gamma\gamma$, an intro.



SM diagrams



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$B_{s,d} \to \gamma\gamma$ decay in the model with one universal extra dimension

G. Devidze [a,1], A. Liparteliani [a,1], Ulf-G. Meißner [b,c,*]

[a] Institute of High Energy Physics and Informatization, 9 University St., 0186 T
[b] Universität Bonn, Helmholtz-Institut für Strahlen- und Kernphysik (Theorie) D-531
[c] Institut für Kernphysik (Theorie), Forschungszentrum Jülich, D-52425 Jülic

Received 6 October 2005; received in revised form 13 January 2006; accepted 13

show that in case of B_s meson decay we can get a difference from SM-result as much as $\sim 3\%$. The pure UED contribution to the $B_s \to \gamma\gamma$ is 3% of the SM estimate and increases the overall contribution (SM + UED) by 3%. The same difference for the case of $B_d \to \gamma\gamma$ is $\sim 6\%$.

Phys. Rev. D **110**, L031106 (2024)

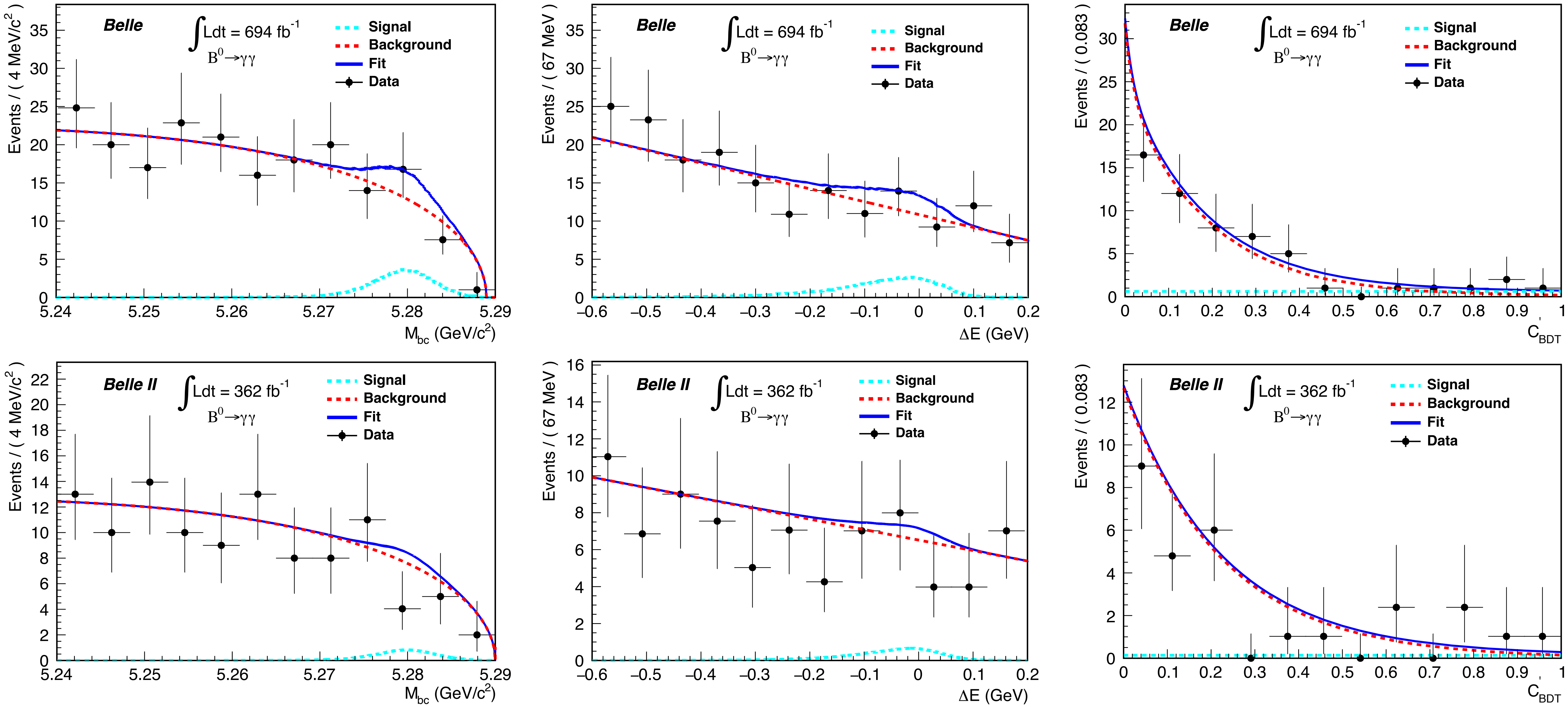


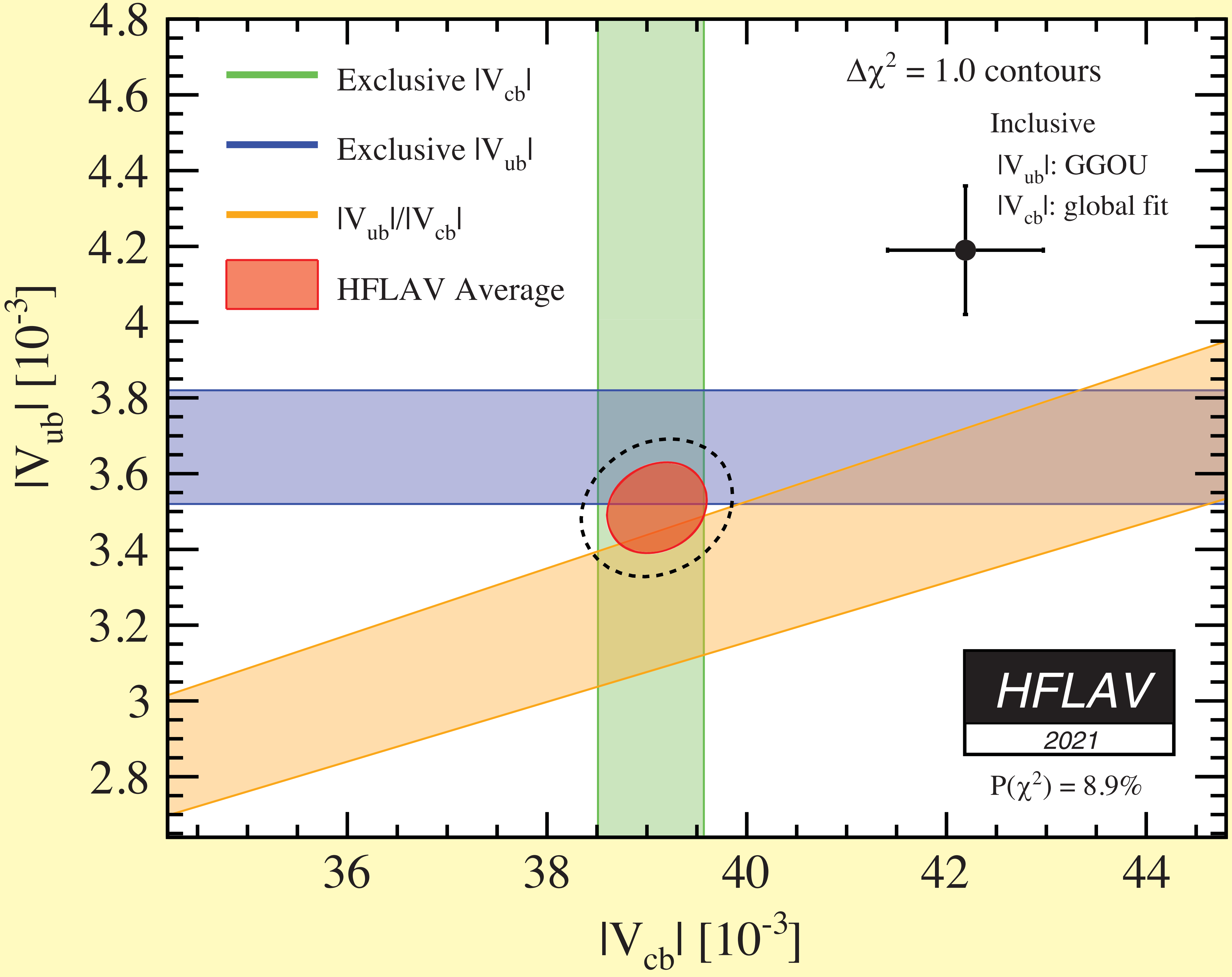
TABLE III. Summary of $\mathcal{B}(B^0 \to \gamma\gamma)$ measurements and UL's at 90% CL.

	$\mathcal{B}(B^0 \to \gamma\gamma)$ significance: 2.5σ	$\mathcal{B}(B^0 \to \gamma\gamma)$ (at 90% CL)
Belle	$(5.4^{+3.3}_{-2.6} \pm 0.5) \times 10^{-8}$	$< 9.9 \times 10^{-8}$
Belle II	$(1.7^{+3.7}_{-2.4} \pm 0.3) \times 10^{-8}$	$< 7.4 \times 10^{-8}$
Combined	$(3.7^{+2.2}_{-1.8} \pm 0.5) \times 10^{-8}$	$< 6.4 \times 10^{-8}$

$B^0 \to \gamma\gamma$

UL based on Bayesian
w/ flat prior in BF

Belle II updates on V_{cb}, V_{ub} saga

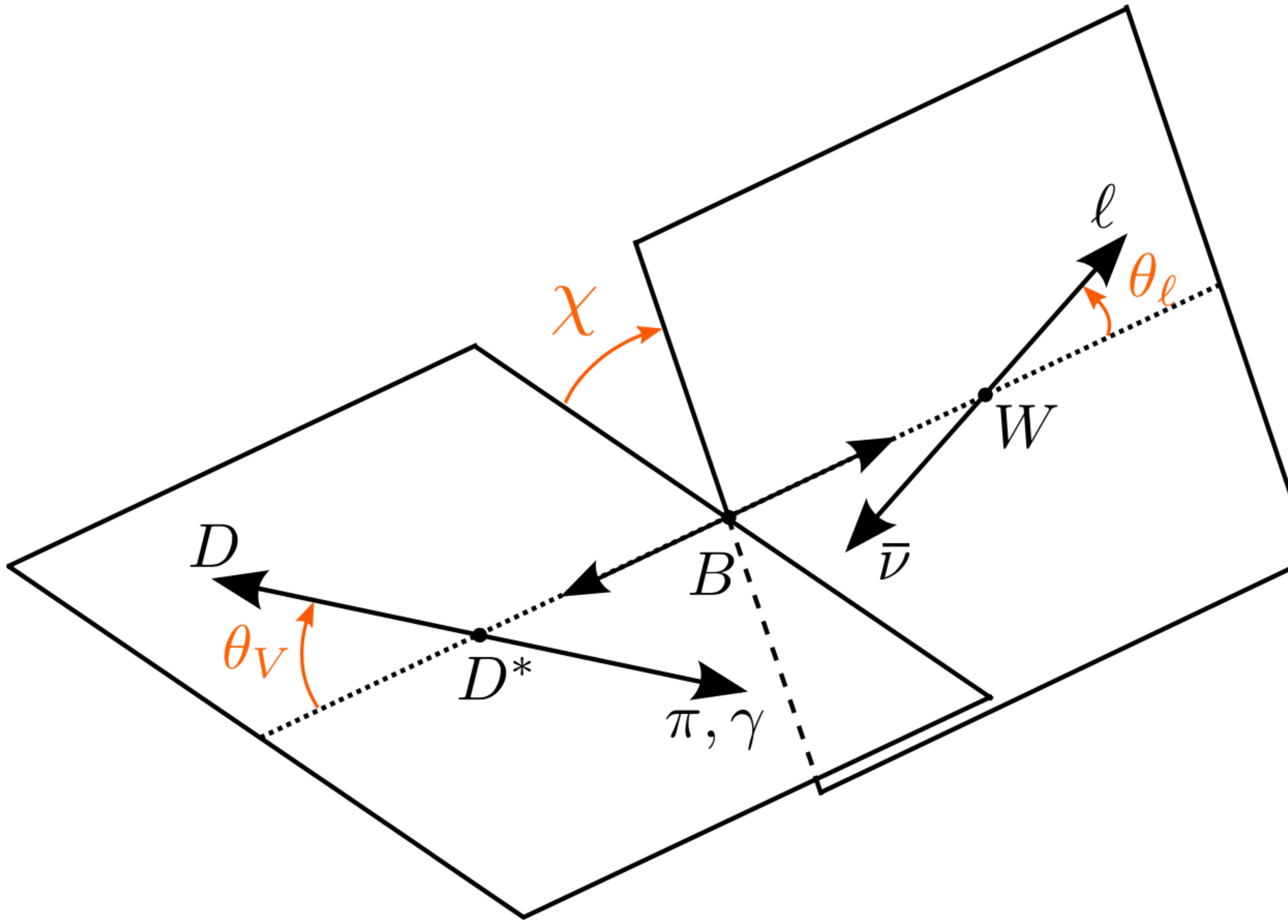


https://doi.org/10.48550/arXiv.2310.20286

$|V_{cb}|$ from angular coeff's of $B \to D^*\ell\nu$

Obtain the differential rates in three angles, θ_ℓ, θ_V, χ, and a kinematic variable, w.

- differential rates are expressed in terms of 12 functions J_i that depend only on w.
- possible for SM test & LFU test



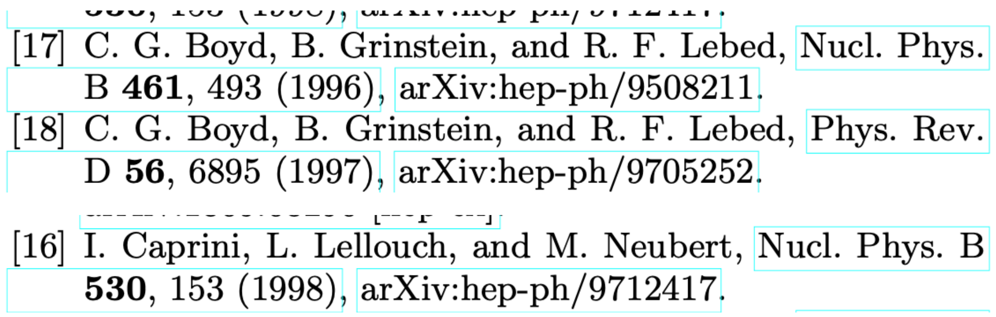
$$w = \frac{m_B^2 + m_{D^*}^2 - q^2}{2 m_B m_{D^*}}$$

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

https://doi.org/10.48550/arXiv.2310.20286

$|V_{cb}|$ from angular coeff's of $B \to D^* \ell \nu$

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



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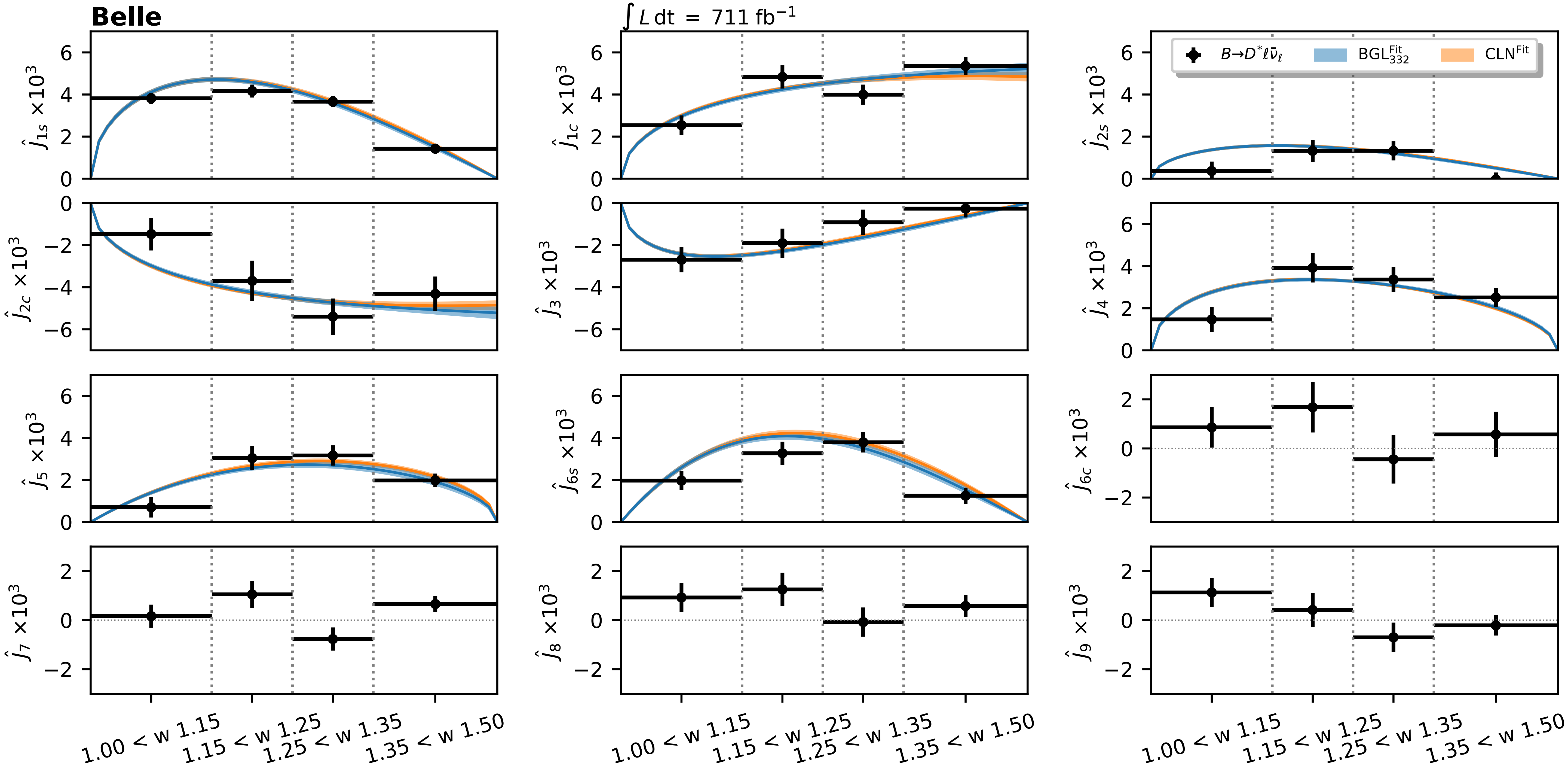

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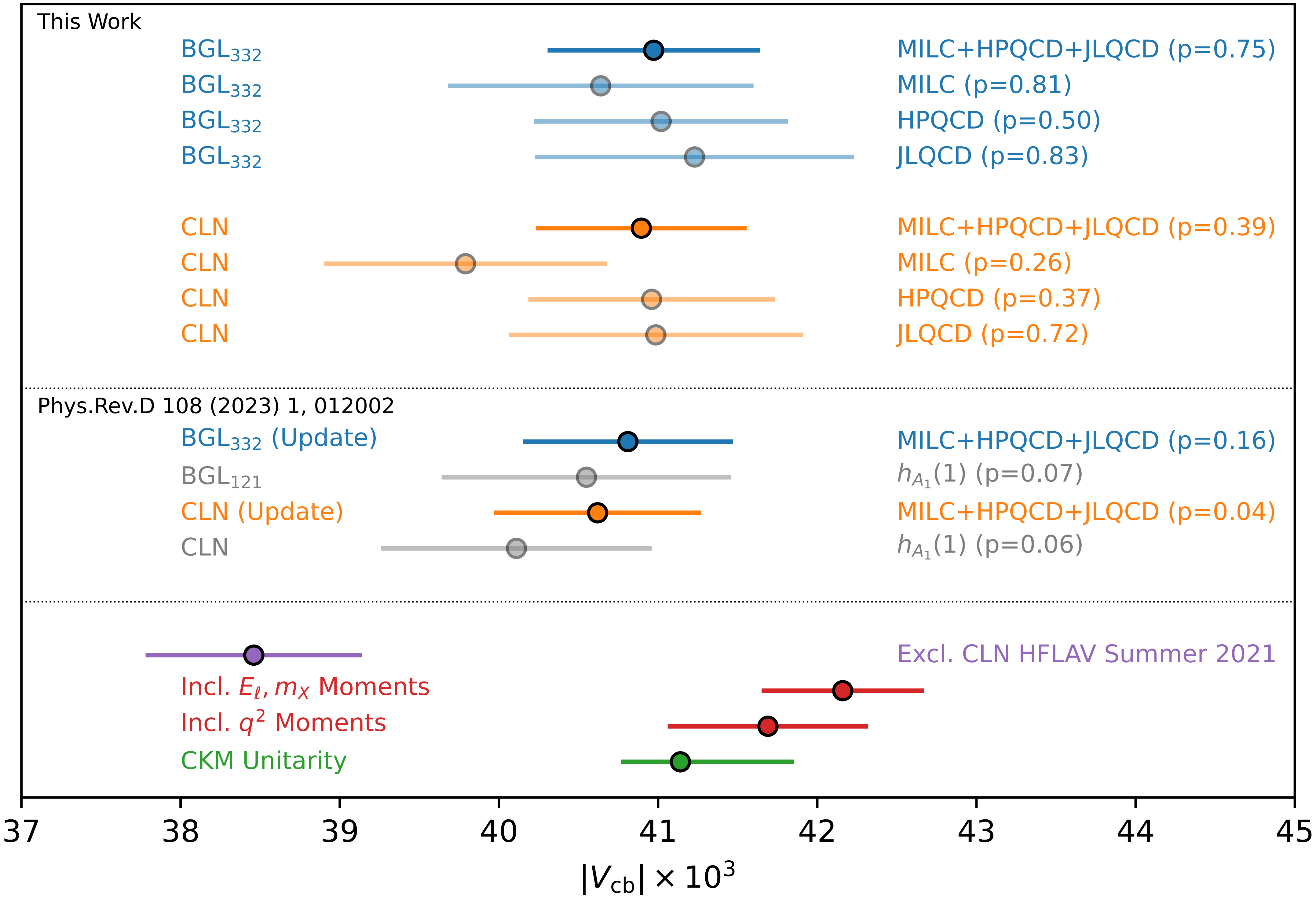

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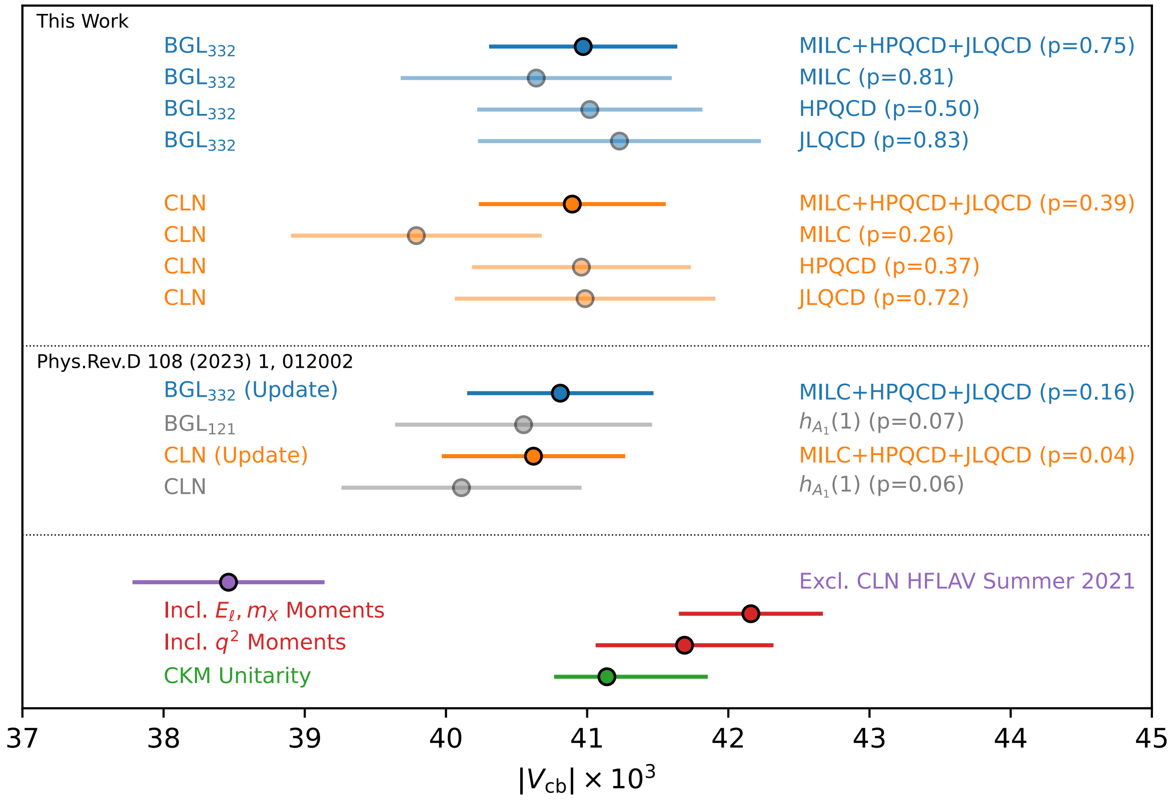
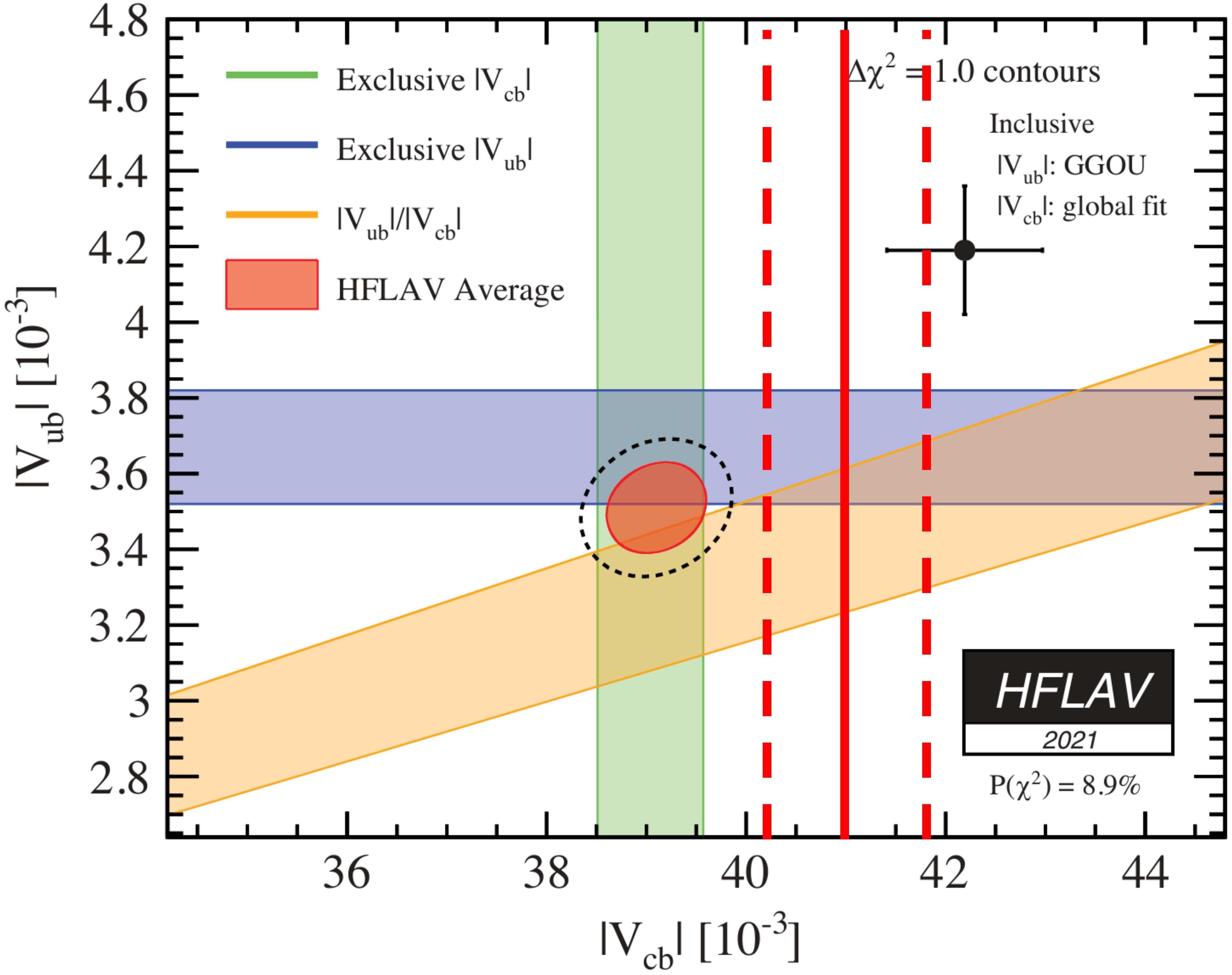
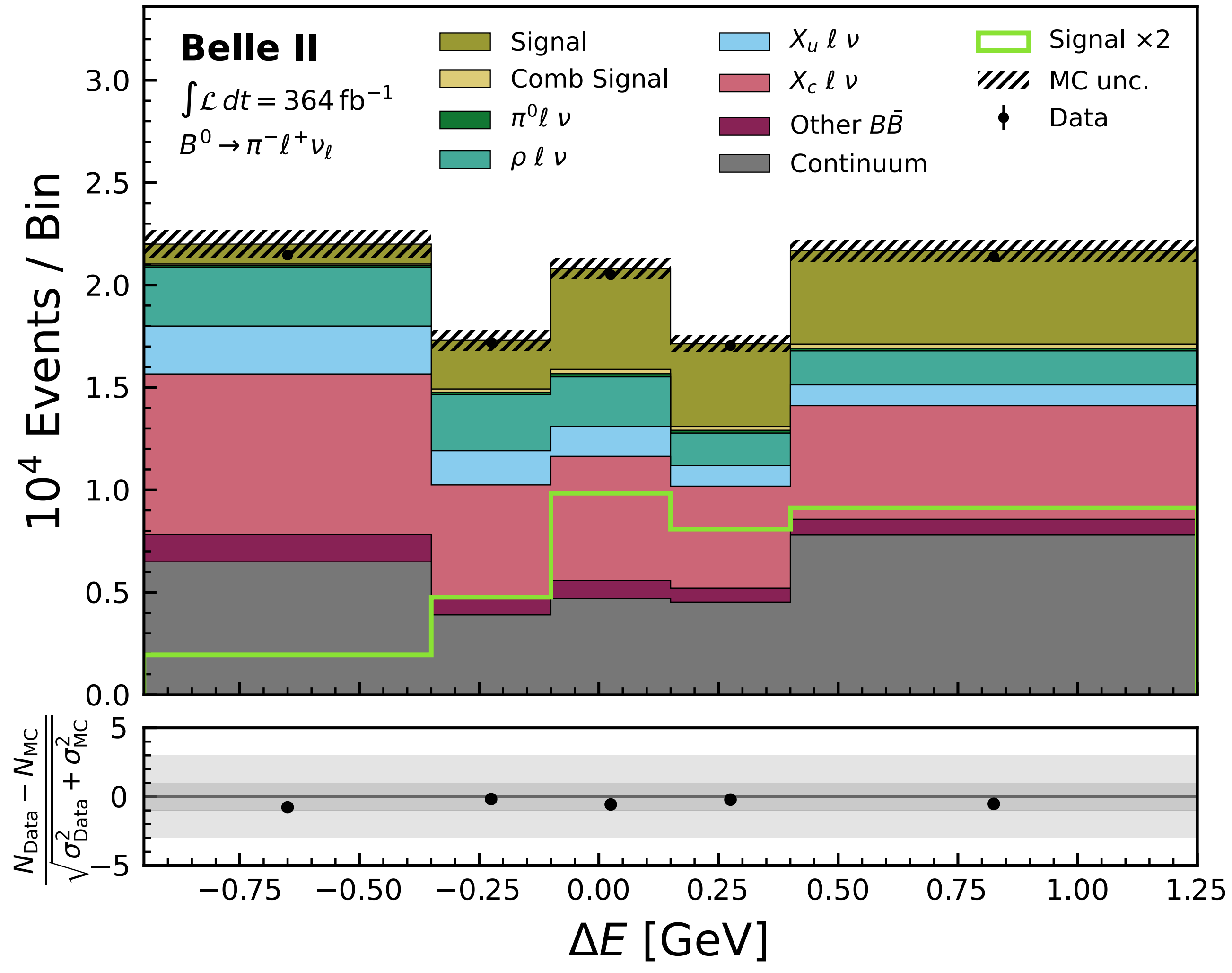


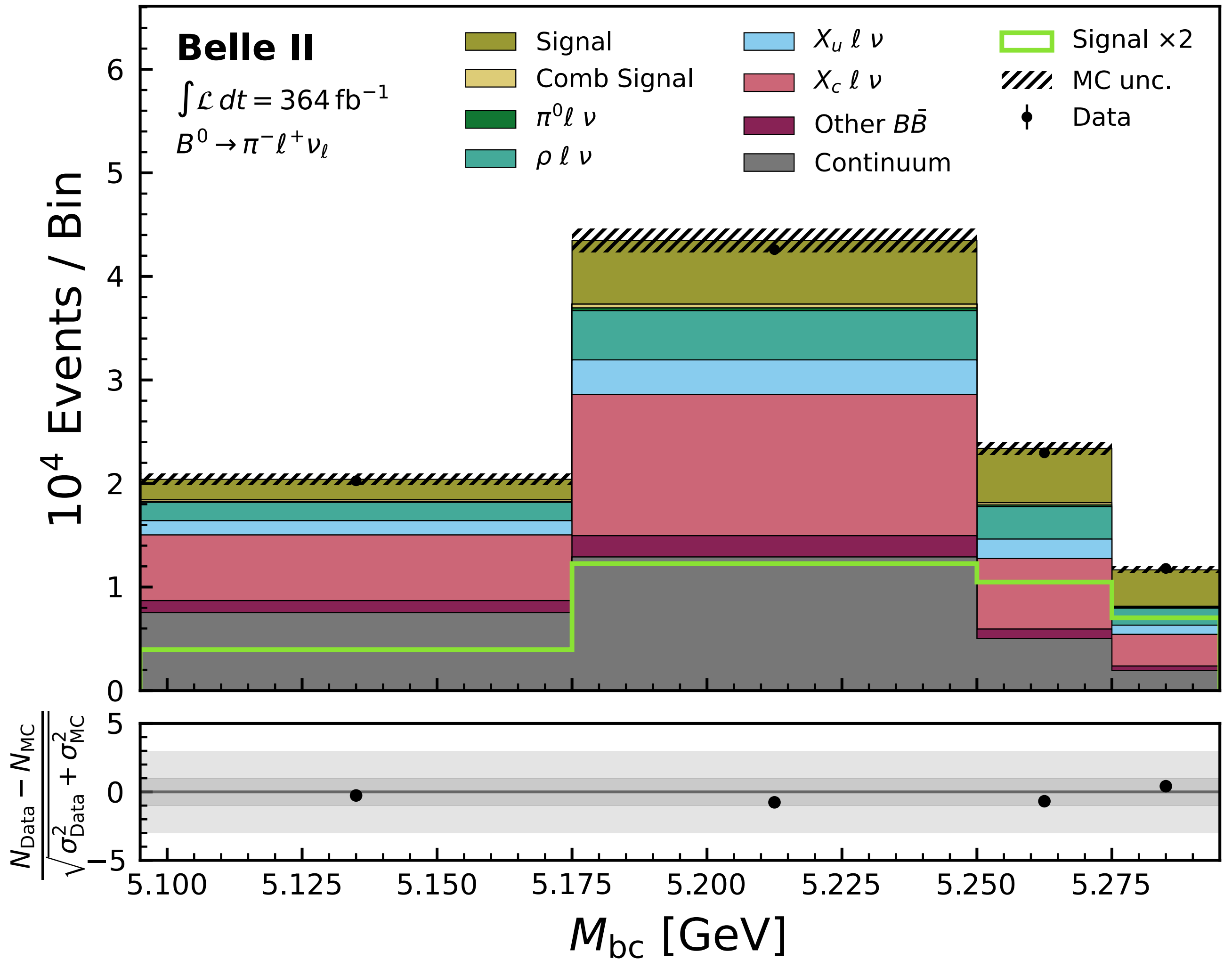


https://doi.org/10.48550/arXiv.2407.17403

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

- **Extract $|V_{ub}|$ by simultaneously fitting $B^0 \to \pi^- \ell^+ \nu$ & $B^+ \to \rho^0 \ell^+ \nu$**
- **Signal extraction in (13+10)x4x5 bins**
  - 13 (10) bins in q^2 for $B^0 \to \pi^- \ell^+ \nu$ ($B^+ \to \rho^0 \ell^+ \nu$)
  - 4 bins in $M_{\rm bc}$, 5 bins in ΔE





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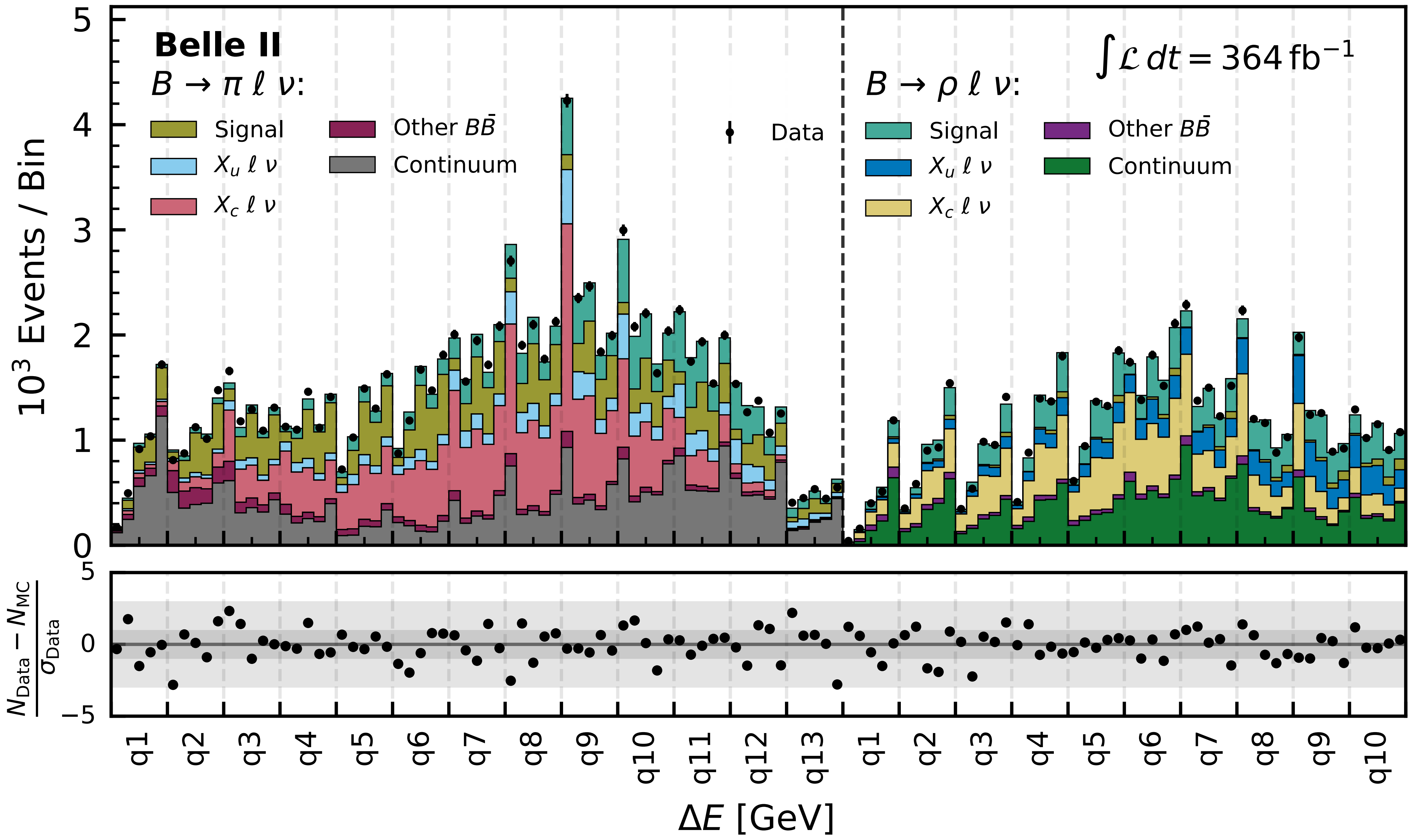
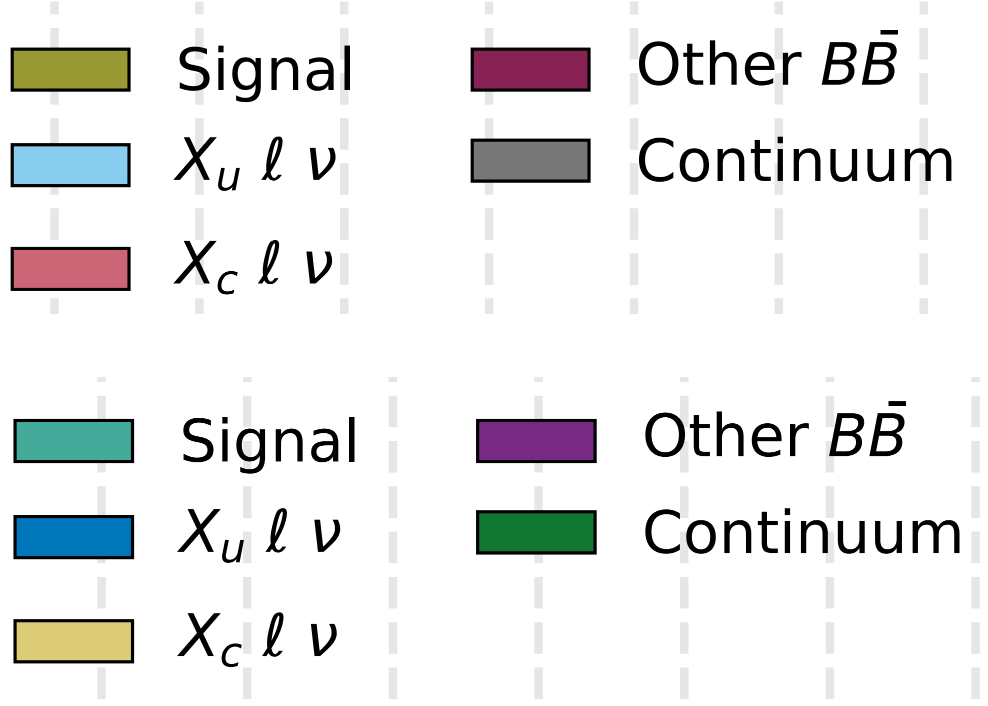
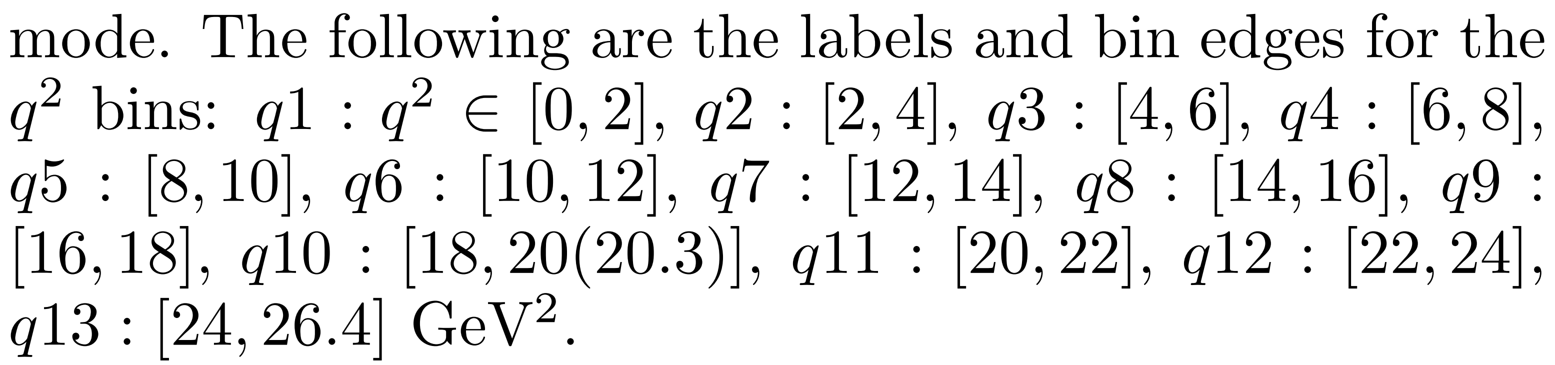
$|V_{ub}|$ from $B^0 \to \pi^- \ell^+ \nu$ & $B^+ \to \rho^0 \ell^+ \nu$

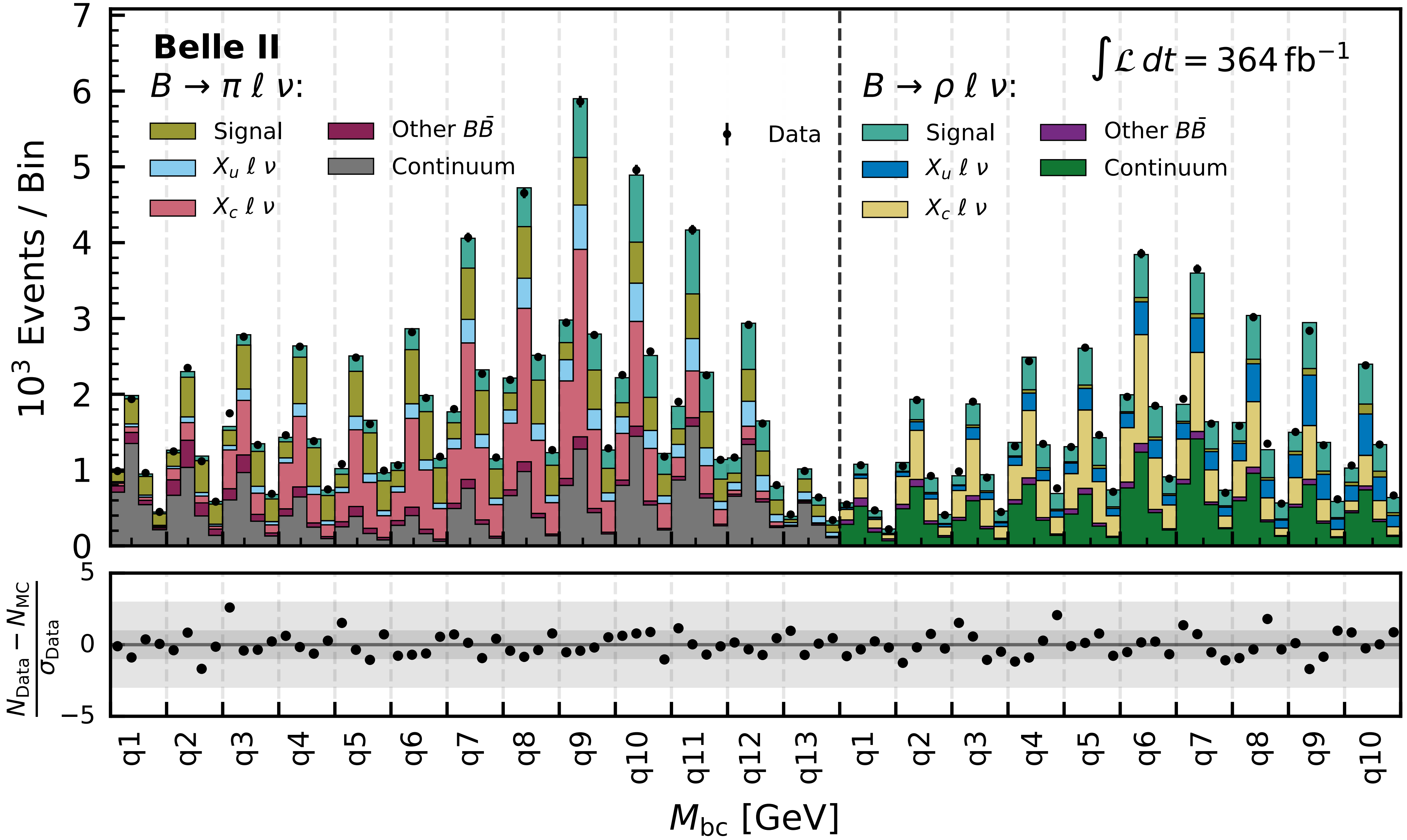


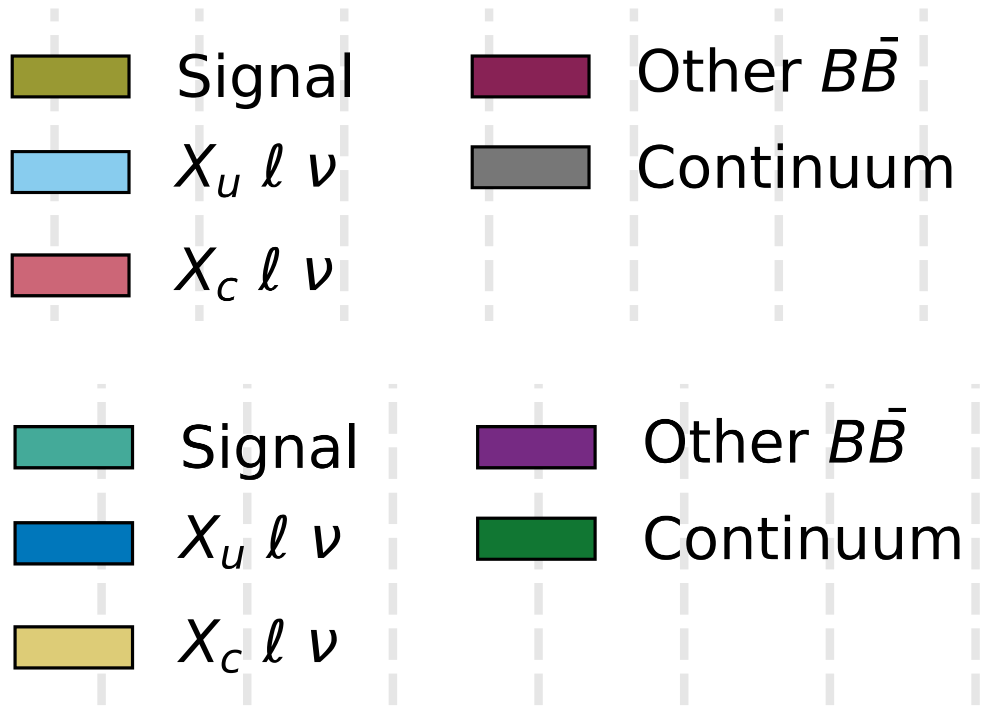


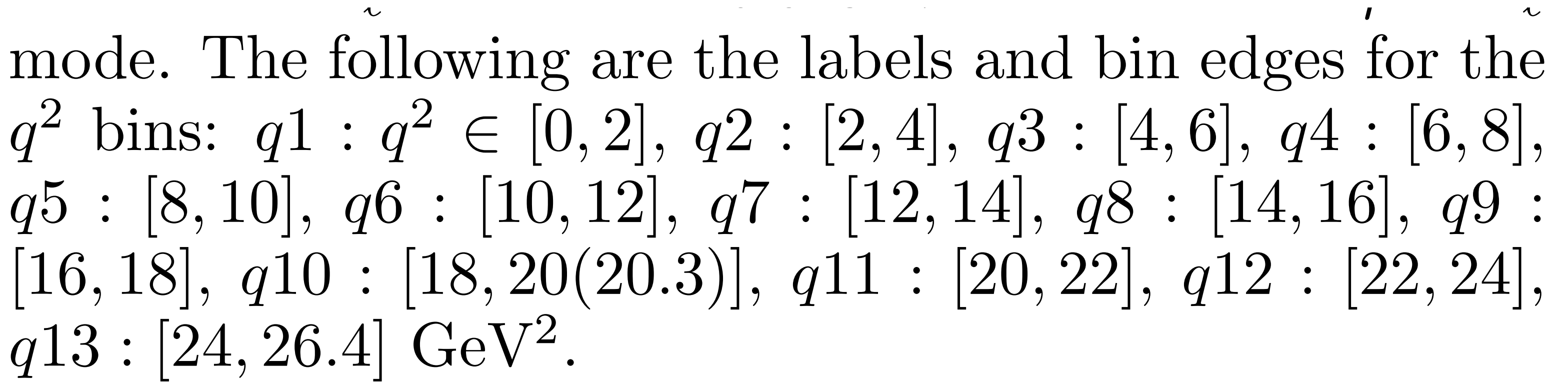

mode. The following are the labels and bin edges for the q^2 bins: $q1 : q^2 \in [0, 2]$, $q2 : [2, 4]$, $q3 : [4, 6]$, $q4 : [6, 8]$, $q5 : [8, 10]$, $q6 : [10, 12]$, $q7 : [12, 14]$, $q8 : [14, 16]$, $q9 : [16, 18]$, $q10 : [18, 20(20.3)]$, $q11 : [20, 22]$, $q12 : [22, 24]$, $q13 : [24, 26.4]$ GeV^2.

https://doi.org/10.48550/arXiv.2407.17403

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







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https://doi.org/10.48550/arXiv.2407.17403

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

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

Total BF by integrating the $\Delta\mathscr{B}(q^2)$

$|V_{ub}|$ extracted separately from $\pi\ell\nu$ and $\rho\ell\nu$ mode using χ^2 fits to the measured q^2 spectra

$$\chi^2 = \sum_{i,j=1}^{N} (\Delta B_i - \Delta\Gamma_i \tau) C_{ij}^{-1} (\Delta B_j - \Delta\Gamma_j \tau) + \sum_m \chi^2_{Theory,m}$$

Form-factor coefficents:

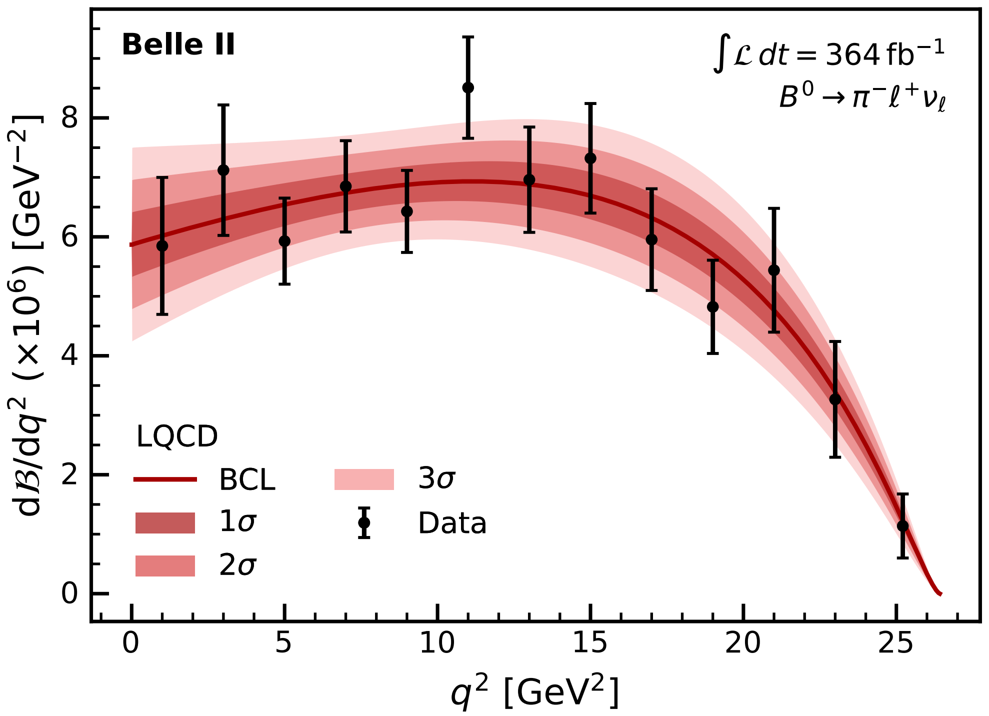
BCL for $B^0 \to \pi^- l^+ \nu_l$ — C. Bourrely, L. Lellouch and I. Caprini. PRD 79 (2009) 013008

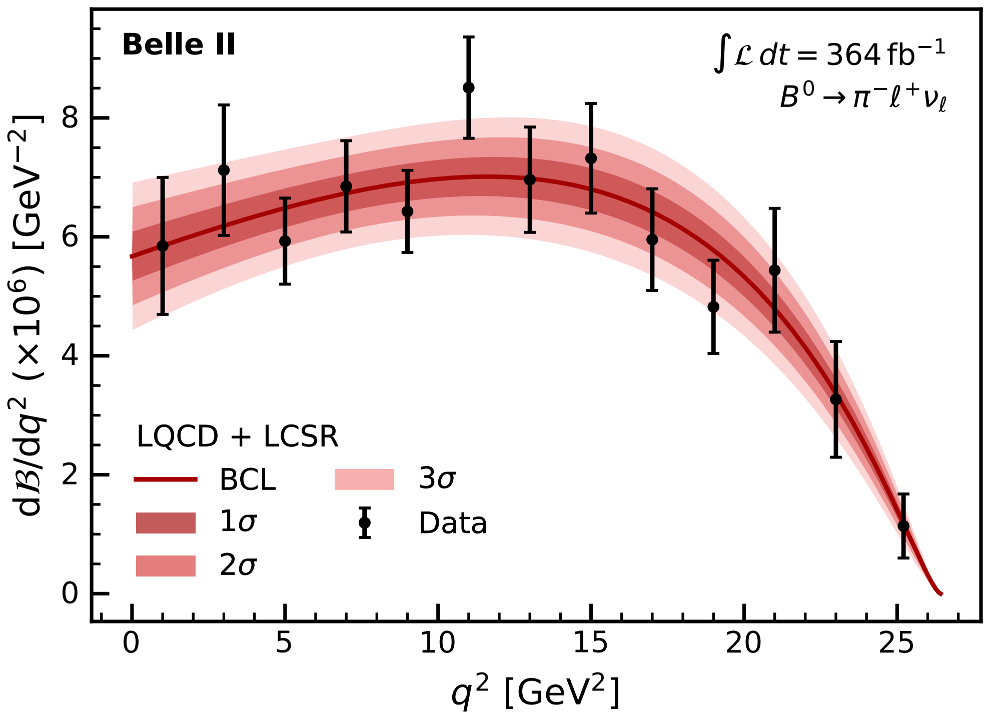
BSZ for $B^+ \to \rho^0 l^+ \nu_l$ — A. Bharucha, D. M. Straub and R. Zwicky, JHEP 08 (2016) 98

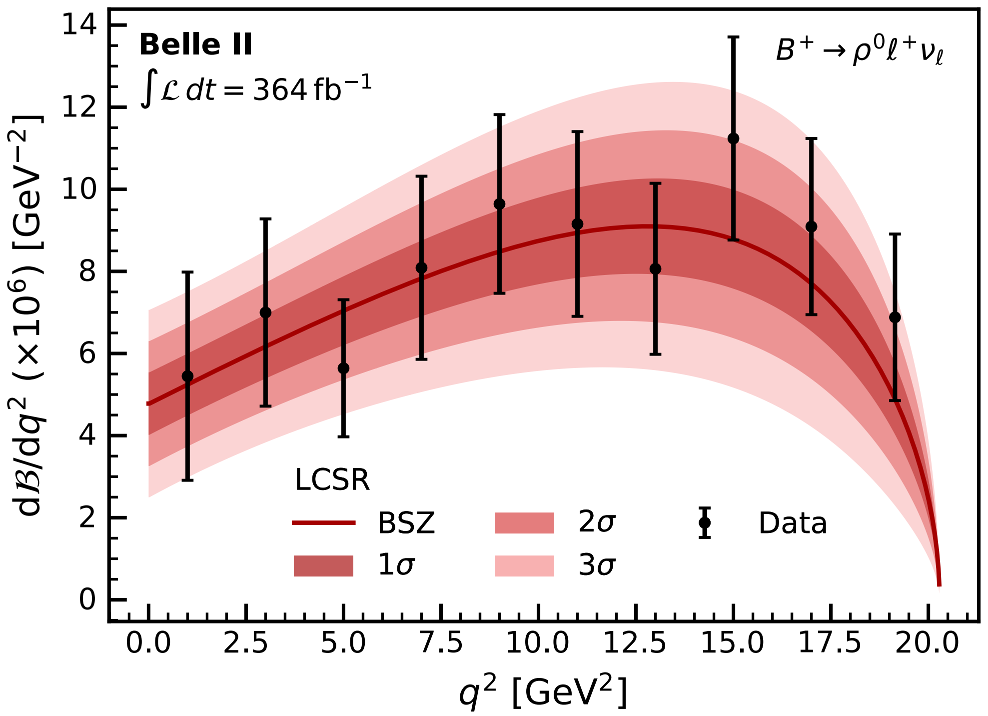
$B^0 \to \pi^- \ell^+ \nu$ (LQCD) $\quad |V_{ub}|_{B\to\pi\ell\nu_\ell} = (3.93 \pm 0.09 \pm 0.13 \pm 0.19) \times 10^{-3}$

$B^0 \to \pi^- \ell^+ \nu$ (LQCD+LCSR) $\quad |V_{ub}|_{B\to\pi\ell\nu_\ell} = (3.73 \pm 0.07 \pm 0.07 \pm 0.16) \times 10^{-3}$

$B^+ \to \rho^0 \ell^+ \nu$ (LCSR) $\quad |V_{ub}|_{B\to\rho\ell\nu_\ell} = (3.19 \pm 0.12 \pm 0.17 \pm 0.26) \times 10^{-3}$







https://doi.org/10.48550/arXiv.2407.17403

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

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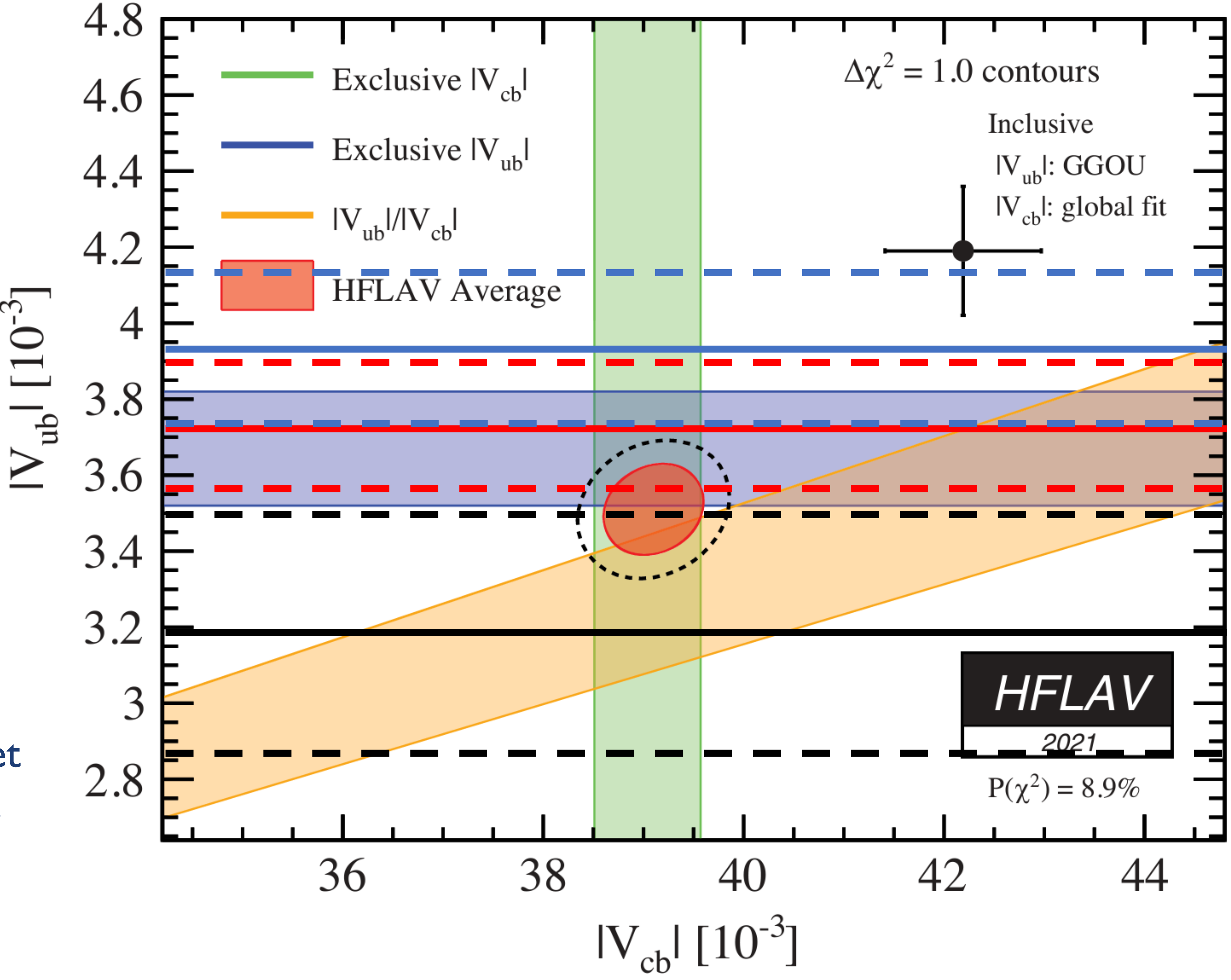
$$|V_{ub}|_{B\to\pi\ell\nu_\ell} = (3.73 \pm 0.07 \pm 0.07 \pm 0.16) \times 10^{-3}$$

$$|V_{ub}|_{B\to\rho\ell\nu_\ell} = (3.19 \pm 0.12 \pm 0.17 \pm 0.26) \times 10^{-3}$$

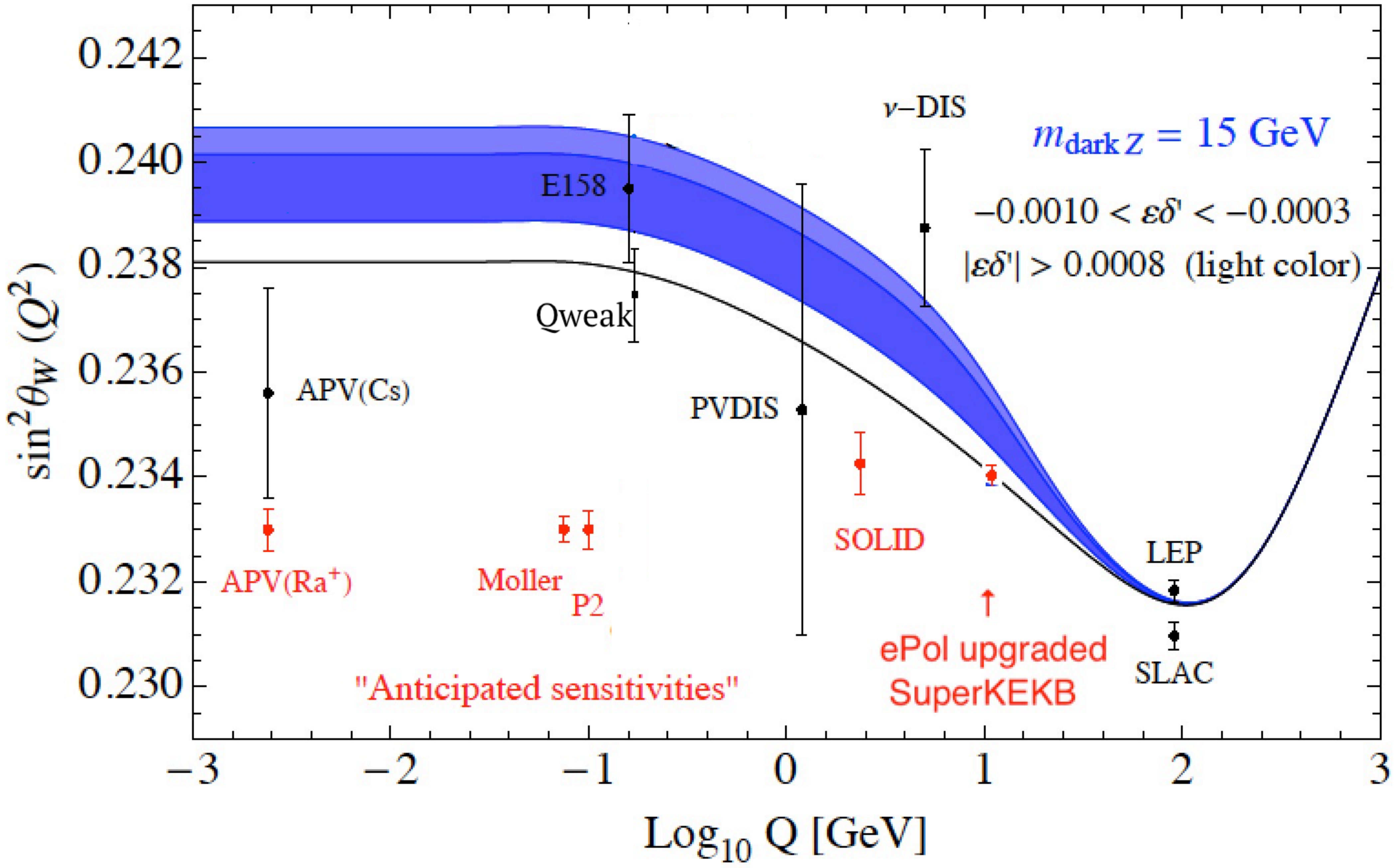


The results are limited by
- size of the off-resonance data set
- non-resonance $B \to X_u \ell \nu$ bkgd,

and reduce the tension against $|V_{ub}|$ inclusive

ChiralBelle for future

Chiral Belle



- Project with polarized e^- beam at SuperKEKB
- Could open new window for discoveries at Belle II
  - new, rich, and unique physics opportunities, e.g. $\sin^2\theta_W$, $(g\text{-}2)_\tau$
  - with no negative impact on the existing program

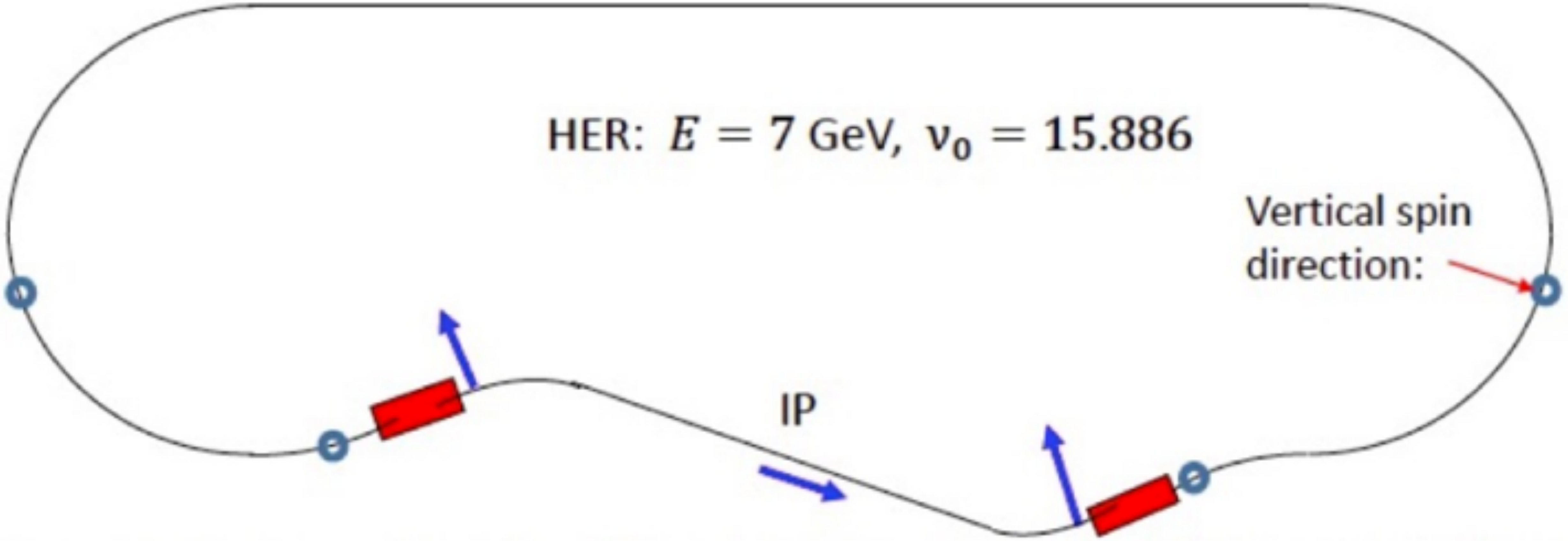
Chiral Belle

NC coupling w/ 70% e^- pol.

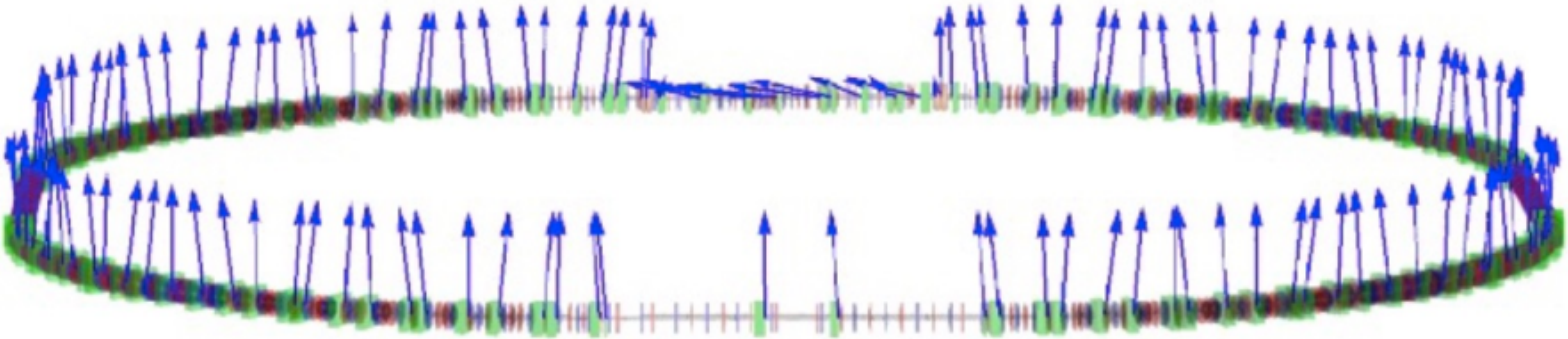
Final State Fermion	SM $g_V^f(M_Z)$	World Average[1] g_V^f	Chiral Belle $\sigma(g_V^f)$ 1 ab^{-1}	Chiral Belle $\sigma(g_V^f)$ 20 ab^{-1}	Chiral Belle $\sigma(g_V^f)$ 40 ab^{-1}	Chiral Belle σ $\sin^2\Theta_W$ 40 ab^{-1}
b-quark (eff.=0.3)	-0.3437±.0001	-0.3220±0.0077 (high by 2.8σ)	0.0022 Improve x3	0.002 Improve x4	0.002	0.003
c-quark (eff. = 0.3)	+0.1920±.0002	+0.1873 ± 0.0070	0.0036 Improve x2	0.001 Improve x6	0.001	0.0008
Tau (eff. = 0.25)	-0.0371 ±.0003	-0.0366 ± 0.0010	0.0049	0.001 (similar)	0.0008	0.0004
Muon (eff. = 0.5)	-0.0371 ±.0003	-0.03667±0.0023	0.0031	0.0007 Improve x 3	0.0005	0.0003
Electron (17nb, eff=0.36)	-0.0371 ±.0003	-0.03816±0.00047	0.0039	0.0009	0.0006	0.0003

1 - Physics Report Vol 427, Nos 5-6 (2006), ALEPH, OPAL, L3, DELPHI, SLD

Spin rotation

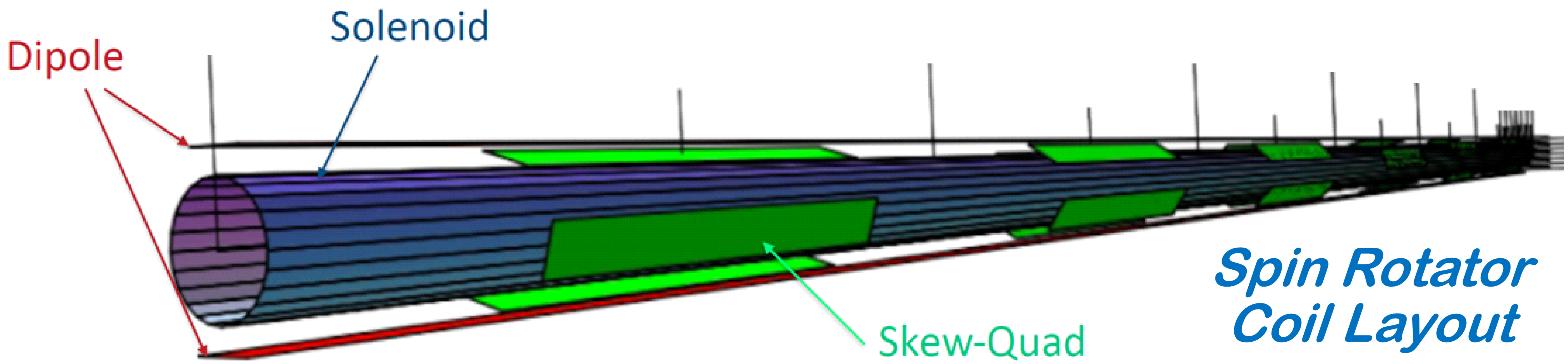


Spin direction is vertical in the main part of HER. Then it is rotated to the horizontal plane by the set of two solenoids, which are comprising the 90^0 spin rotator.



Chiral Belle

Spin rotation



Spin Rotator Coil Layout

Figure 29: Uli Wienands' (ANL) concept for a compact combined function spin rotator unit with overlaid dipole, solenoid and skew-quadrupole superconducting coil fields.

Closing remarks

- Belle II has collected over $0.4\ \mathrm{ab}^{-1}$ data sample in its first 3 years of operation before LS1, and started Run 2 data taking in Feb. this year.
- With the data set of ~1/2 the size of Belle, the physics precision of Belle II results are comparable or better in many analyses.
- Recent Belle II physics highlights include first evidence for $B^+ \to K^+\nu\bar{\nu}$, and inclusive test of LFU with $B \to X\tau\nu$.
- Belle II also started her endeavor to understand the 'Incl.-Excl. tension' on $|V_{ub}|$ and $|V_{cb}|$.
- Run 2 is underway with the goal of collecting a several ab^{-1} data in the next few years. Please stay tuned!

Thank you!