Recent results on new physics at Belle and Belle II

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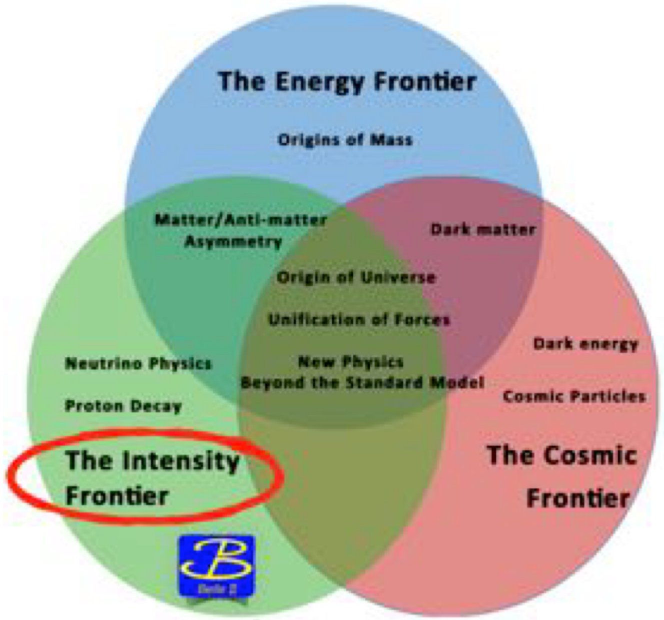
On Behalf of the Belle/Belle II Collaboration

Aug. 26-30, 2024
New Physics Group Worshop (NPG Workshop 2024)
Hangzhou

Physics beyond SM

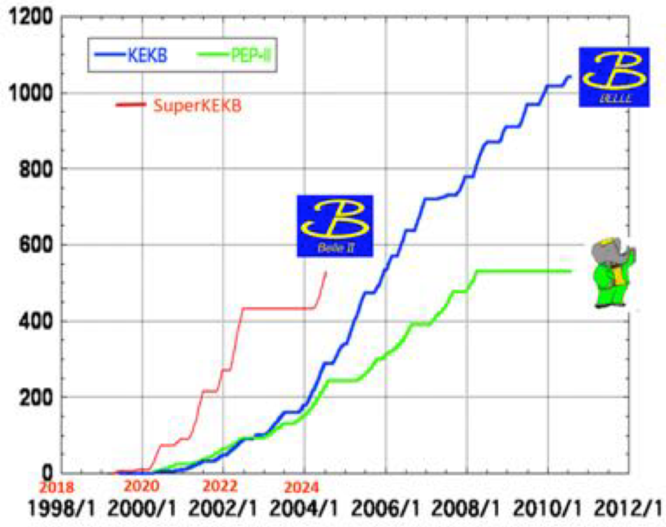
- Different ways of hunting for new physics
- Belle/Belle II operate at the "Intensity Frontier"
  - ✓ Key words: High-precision measurement, probing the SM indirectly
  - ✓ e.g. Deviations from SM predictions
  - ✓ e.g. Measurement of the SM-forbidden or suppressed process
- B-Factories:

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



Physics Frontiers

Belle	KEKB	*06/1999 - 06/2010*
BaBar	PEPII	*10/1999 - 04/2008*
Belle II	SuperKEKB	*03/2019 - current*

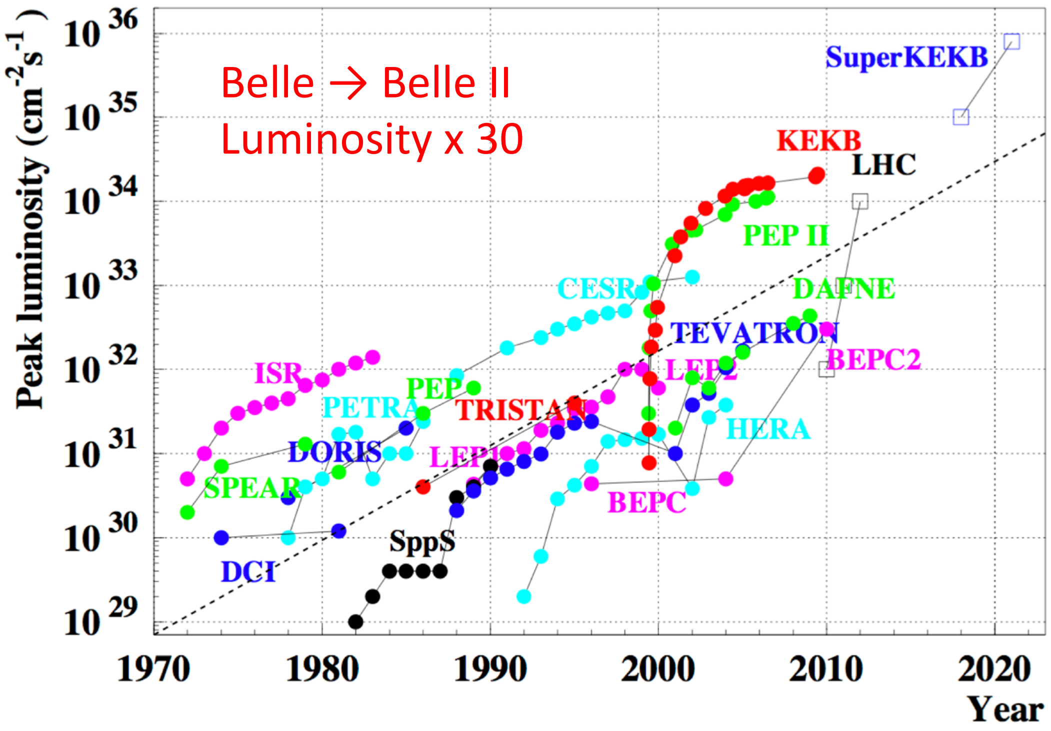


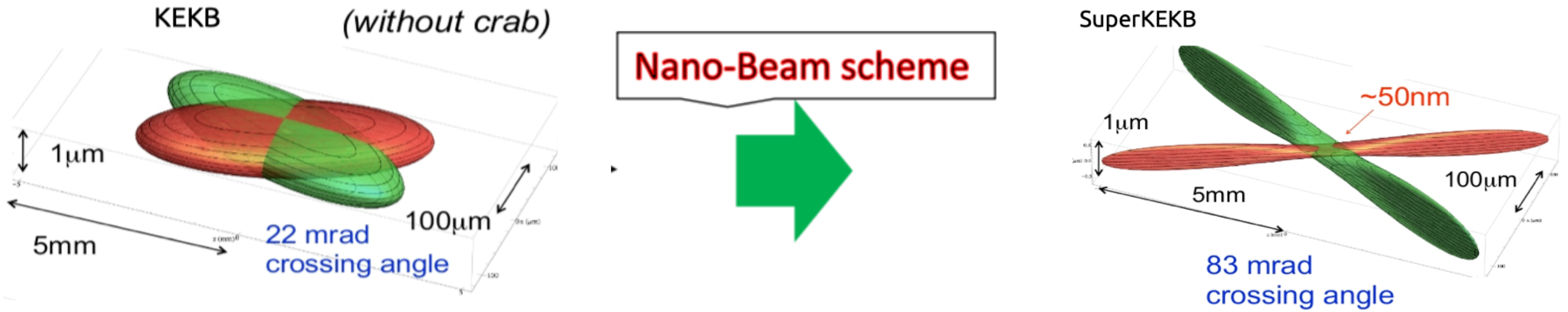
SuperKEKB Accelerator

- Reduction in the beam size by 1/20 at the IP.
- 1.5 times increase in beam currents.

Targets:
Peak luminosity: $6\times10^{35}cm^{-2}s^{-1}$
Integrated luminosity: **50ab^{-1} by 2031**

Achieved 4.7×10^{34} cm^{-2}s^{-1}
(current world record, June 2022)





The Belle/Belle II Detector

Belle II

2019 - current

Vertex: **+ 2-layer PXD** (Pixel Detector)

4-layer SVD (Silicon Vertex detector)

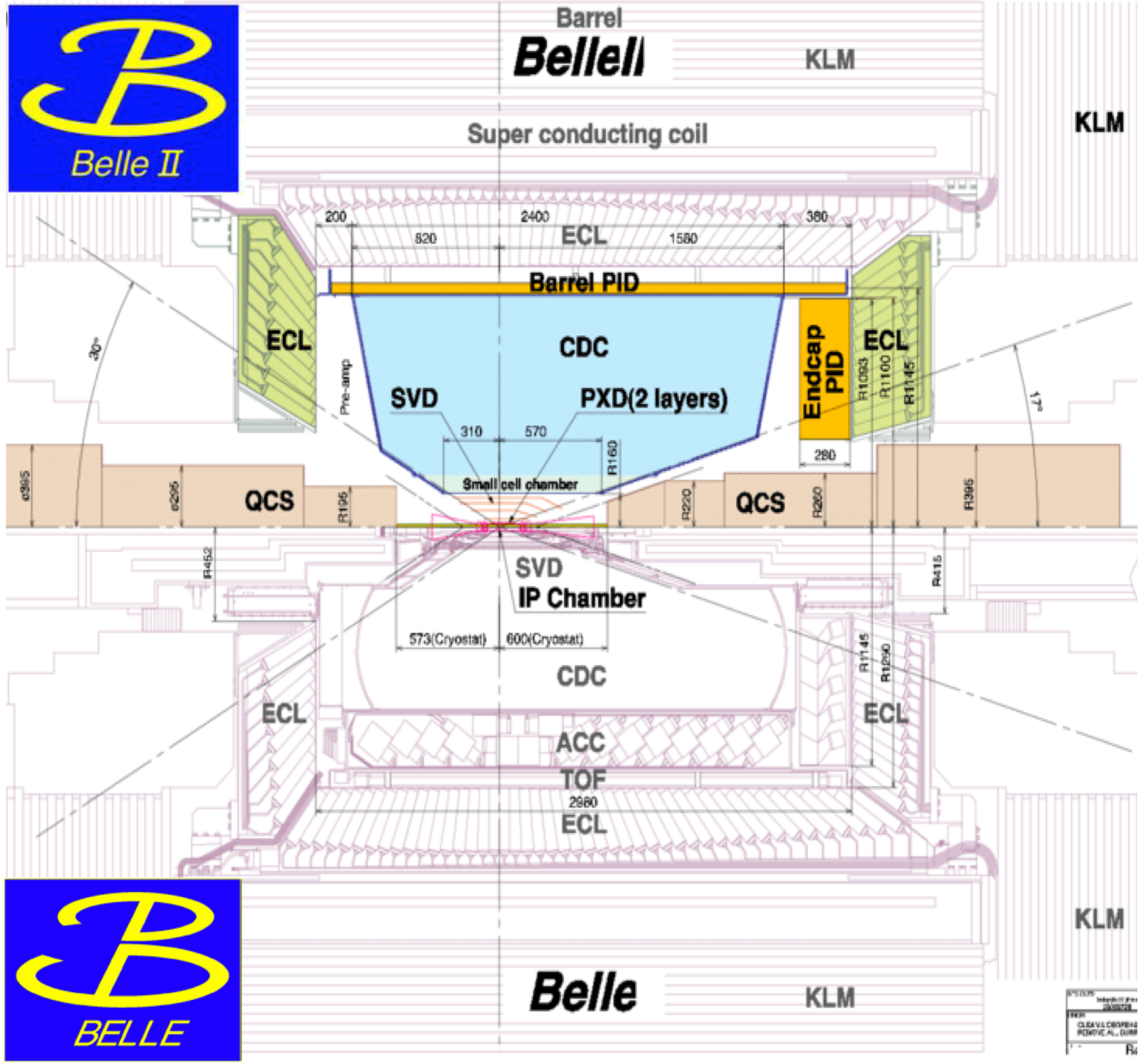
CDC(central drift chamber): Larger volume, smaller drift cell. Faster electronics

PID: (Particle Identification) More compact, better K/pi separation under higher background level

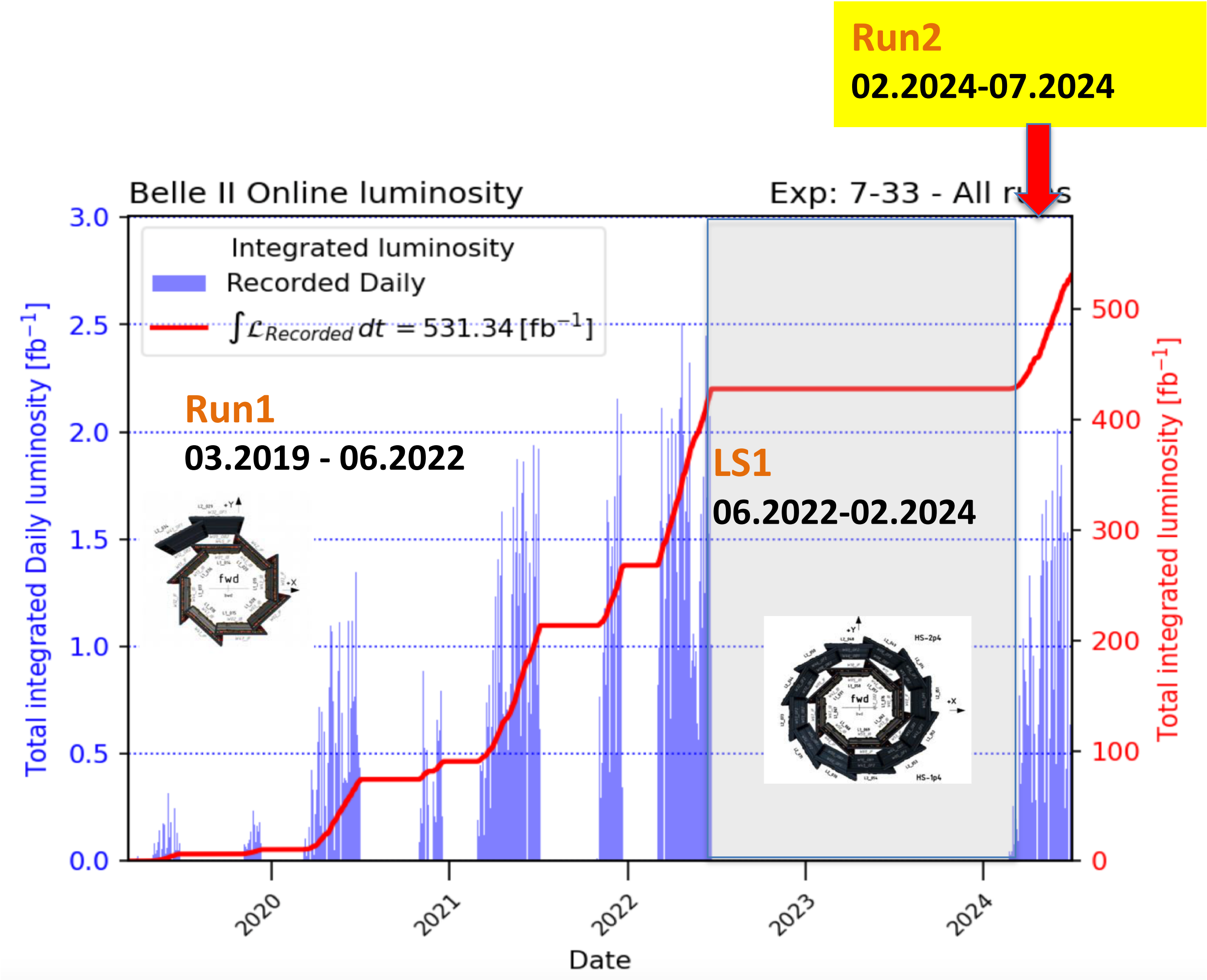
ECL: (electromagnetic Calorimeter) Updated electronics

Belle

1999 - 2010



Status of Belle II data taking



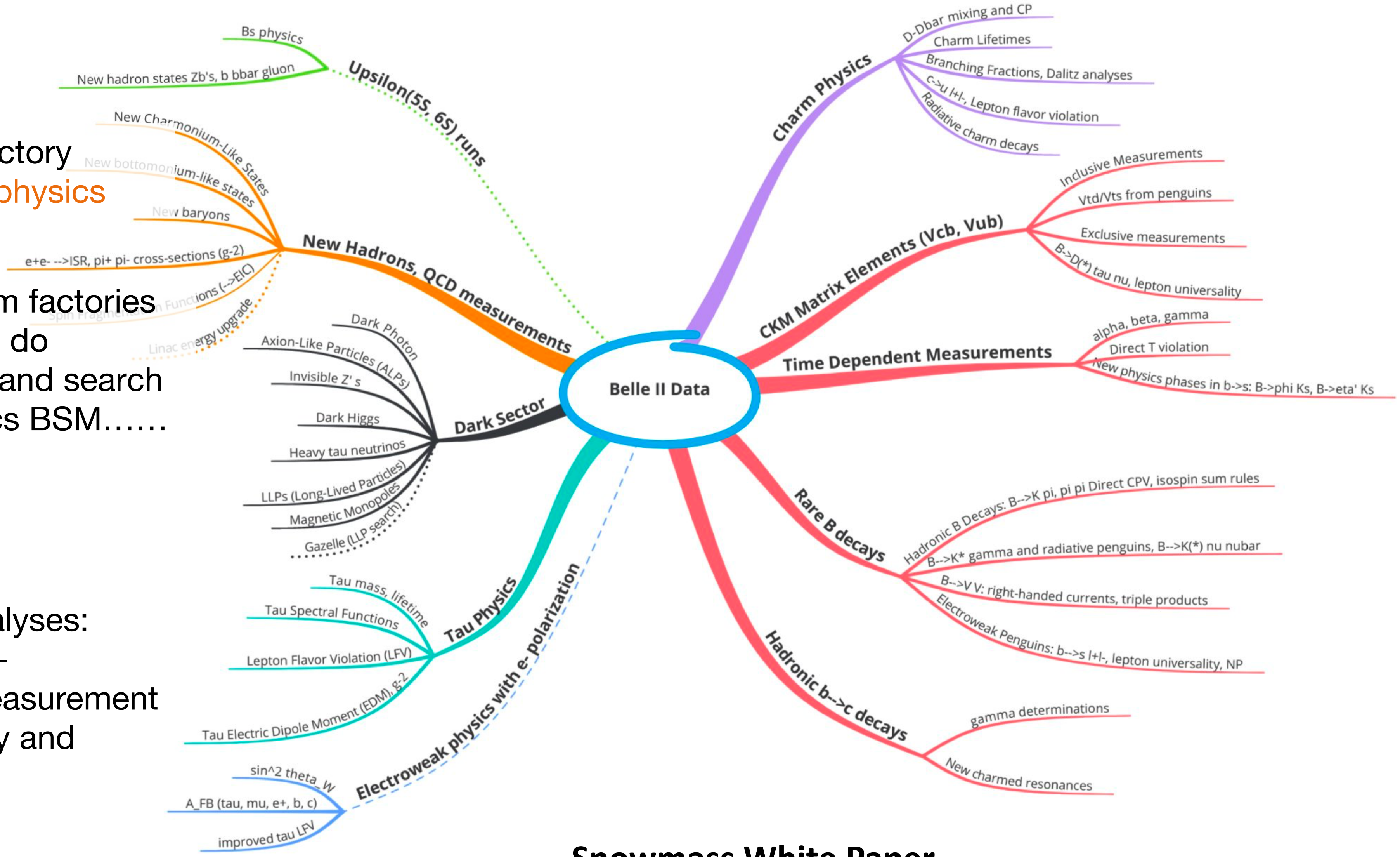
- Run1 from spring 2019 (424 fb^{-1} recorded)
- LS1 motivated by the installation of the 2-layer PXD
  - Replacement of beam-pipe
  - Replacement the photomultipliers of the TOP
  - Improved CDC gas distribution and monitoring system
  - DAQ upgrade …
- Resumed data-taking at early 2024:
  - So far: > 100 fb^{-1} collected
  - ~90% data taking efficiency
- Current issue: Sudden beam loss leading to large dose in the interaction region: -
  - PXD was turned off as a precautionary measure
  - Preventing reaching higher currents
  - Operating stably at 4.5×10^{34} cm^{-2} s^{-1}

Belle and Belle II physics program

Primarily a B factory
But not only B physics

- Also tau, charm factories
- Clean place to do spectroscopy and search for new physics BSM……

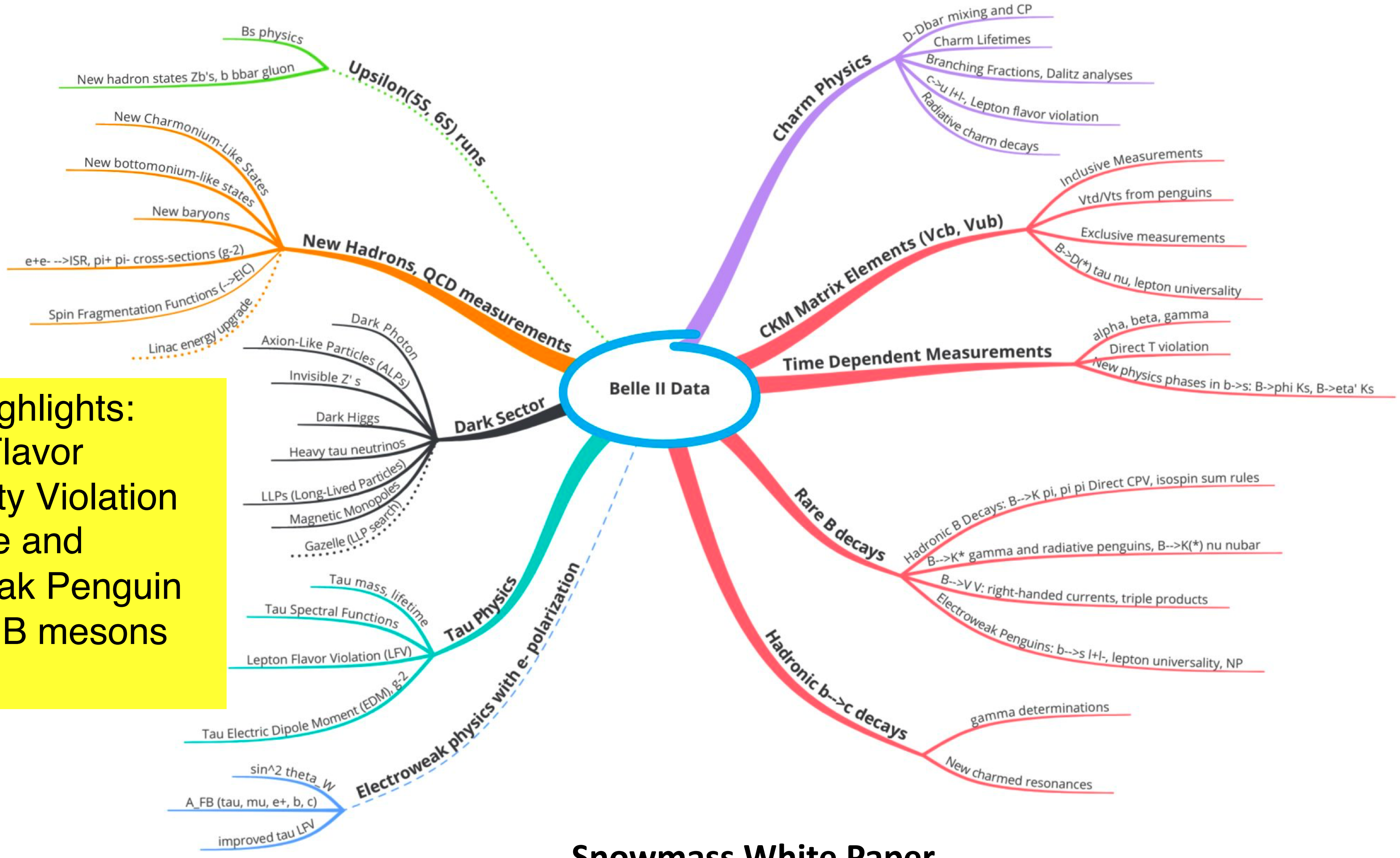
Varies type of analyses:
- Life time, time-dependent measurement
- Missing energy and missing mass



Snowmass White Paper

Belle and Belle II physics program

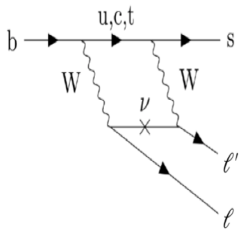
Recent Highlights:
- Lepton Flavor Universality Violation
- Radiative and Electroweak Penguin decays of B mesons
- ……

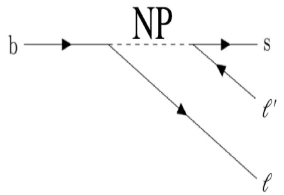


Snowmass White Paper

Test of Lepton Flavor Universality

LFUV AND B Anomalies



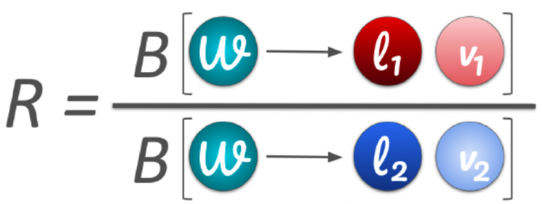


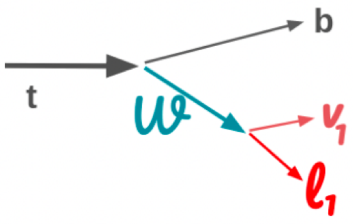
- Lepton Flavor Violating (LFV) decays:
  - ✓ Forbidden in the Standard Model w/o neutrino-oscillation
  - ✓ Can occur via ν mixing but are highly suppressed $(\frac{m_\nu^2}{m_W^2})$
    - well beyond any experimental sensitivity
- Recent measurements of b-hadron decays have provided experimental indications of the lepton flavor universality violation (LFUV) - deviations from:
  - ✓ μ/e universality in b→ sll neutral-current transitions
  - ✓ τ/μ (and τ/e) universality in b → $cl\nu$ charged-current transitions
- LFUV is often accompanied by lepton flavor violation (LFV) in theoretical models (PRL 114 (2015), 091801)
- The observation of LFUV or LFV in the charged sector would be a clear sign of physics beyond the Standard Model! LFUV experimental bounds can be intepreted as constraints on New Physics

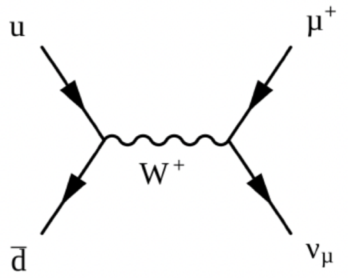
How can we observe LFUV

- Measure ratios of processes with different leptons to reduce systematics

A.Knue







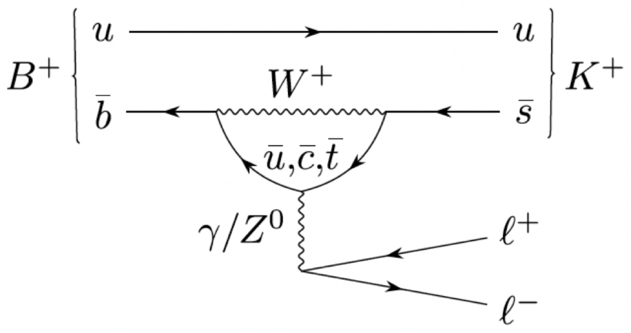
W and Z decays

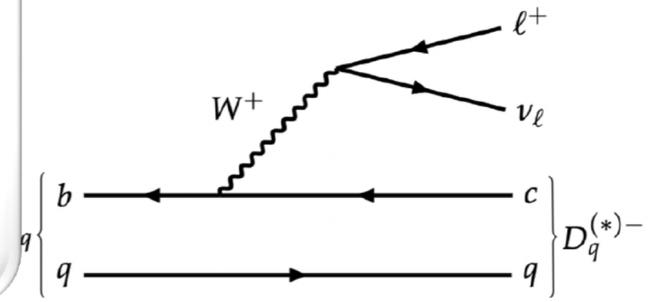
Leptonic decays of strange, charm, beauty hadrons, and tau

LFUV

Semileptonic decays of strange, charm and beauty hadrons

Rare decays of beauty hadrons





Charge conjugated processes implied

Test of LFU with inclusive semitauonic B decay

The $b \to c\tau\nu$ excess

Q: *What if the "anomaly" is just a shared systematic?*

Or a problem with the (shared) theory description?

Is there anything we can do except ***measure R(D) and R(D*) over and over again****?*

$$R(H_{\tau/l}) = \frac{\mathcal{B}(B \to H\tau\nu_\tau)}{\mathcal{B}(B \to Hl\nu_l)}$$

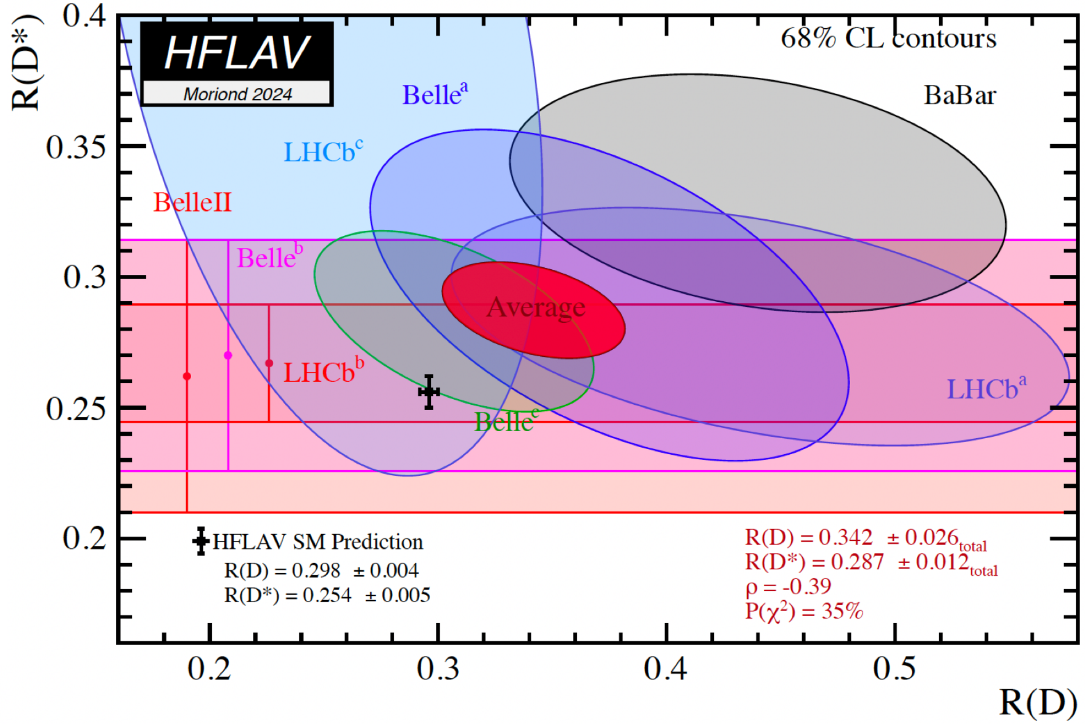
Where $H = D, D^*, X, \pi, etc.$ and $l = e, \mu$

"Traditional" modes

Tension of $R(D^{(*)})$ with SM ~3σ

New

Moriond 2024 - HFLAV



R(D) and R(D*) combined average:
- 3.31 σ tension with the SM prediction considering the correlation

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

First measurement of $R(X_{\tau/\ell})$ as an inclusive test of the $b \to c\tau\nu$ anomaly

Phys. Rev. Lett.132.211804 (2024)

A followup to last-year's *light* lepton ratio $R(X_{\mu/e})$, a first

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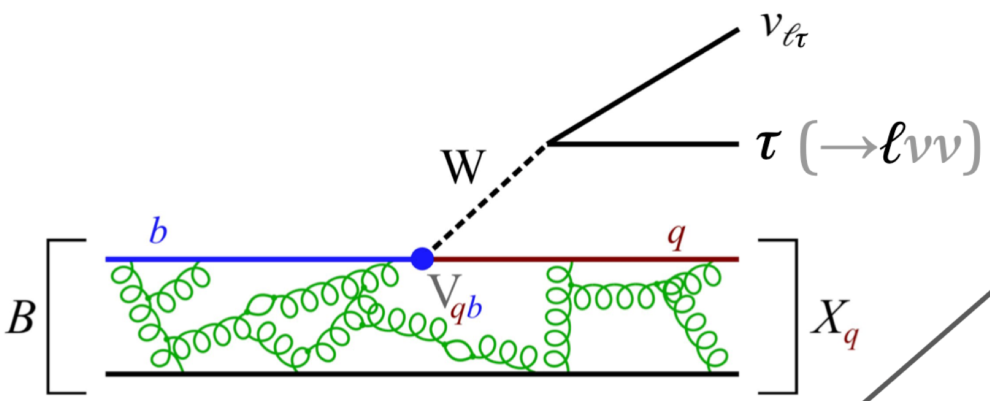
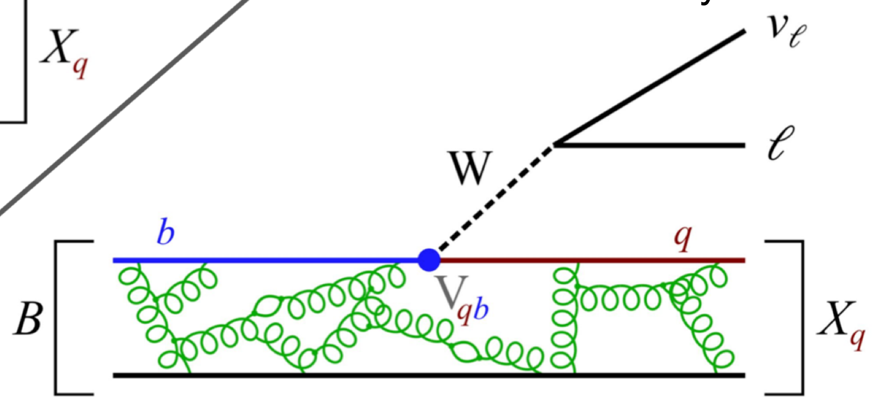
Test of Light-Lepton Universality in the Rates of Inclusive Semileptonic B-Meson Decays at Belle II

L. Aggarwal *et al.* (Belle II Collaboration)
Phys. Rev. Lett. **131**, 051804 – Published 2 August 2023

Physics See synopsis: Standard Model Stays Strong for Leptons

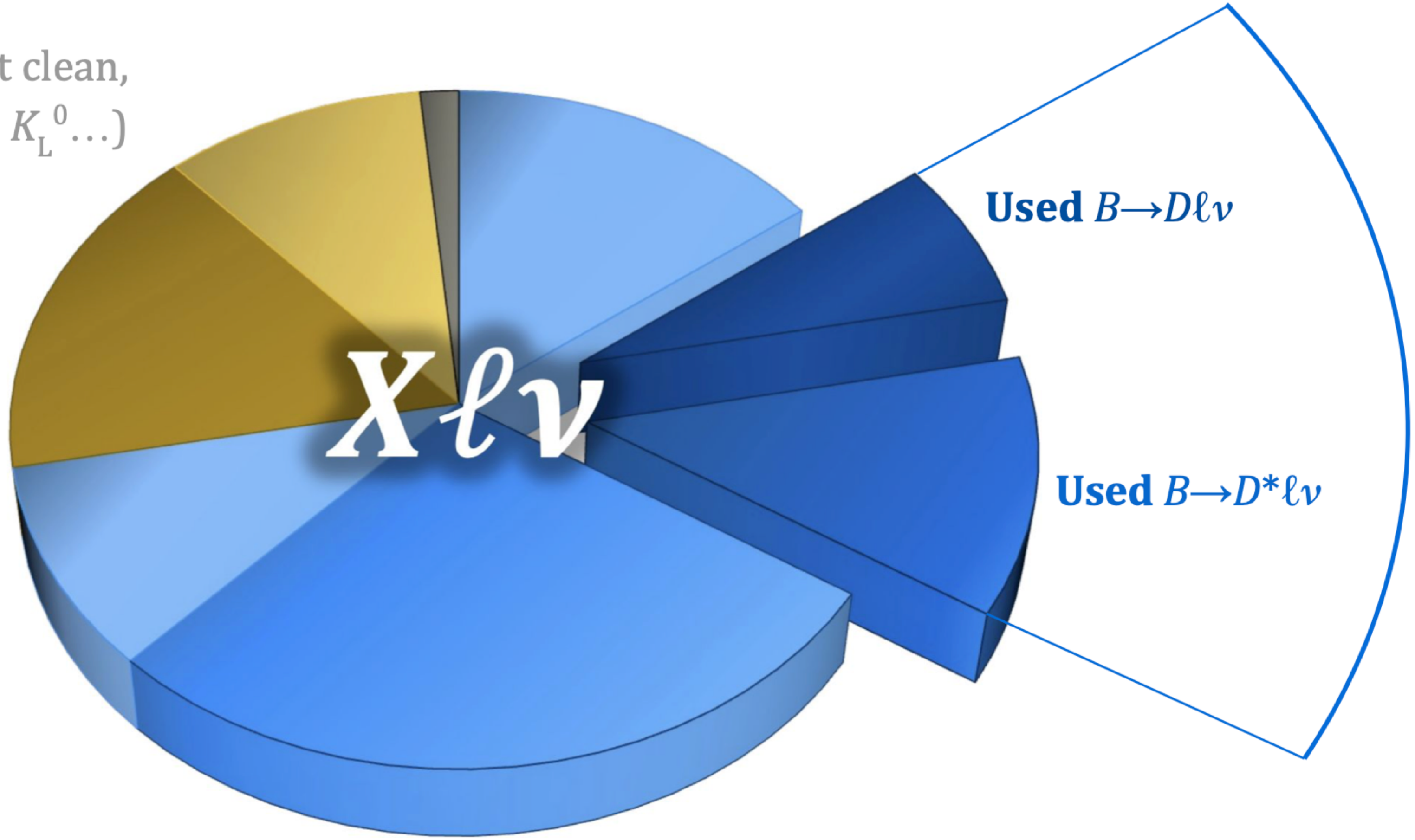
Phys. Rev. Lett.131.051804 (2023)





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

(**not well-known**, not clean, missing ν, K_L^0…)



Used: <20%

Well-known, clean decays (mostly $K^\pm$,$\pi^\pm$)

No missing particles

*So then: how can we use "**not well-known**" as the signal?*

This measurement is statistically and theoretically distinct from R(D$^{(*)}$), and is potentially more precise.

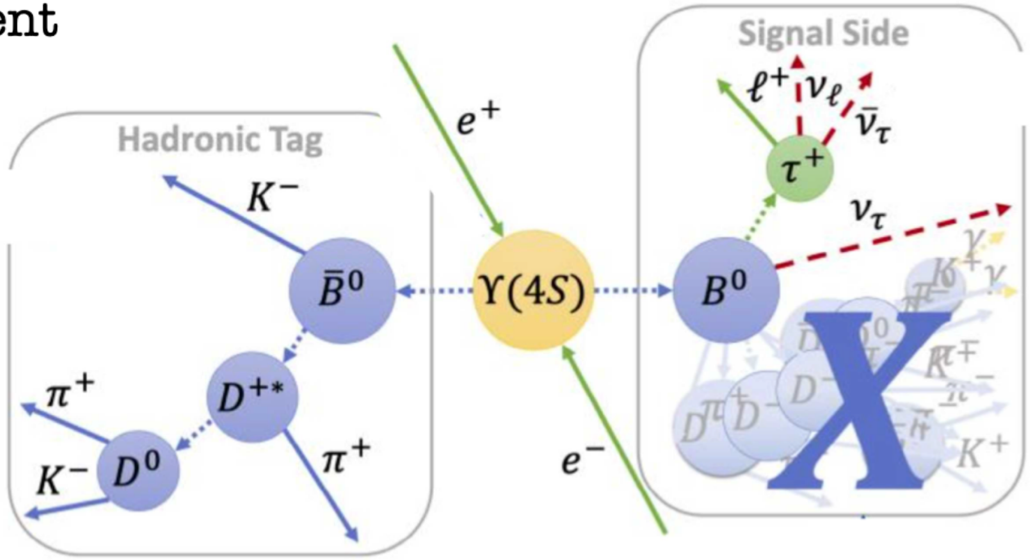
Measurement of $R(X_{\tau/l})$

- Possible to compare the inclusive rates
- Tag B reconstructed using FEI method
- Search for the signal B in the rest of the event
  - Leptonic $\tau \to e/\mu\bar{\nu}\nu$ decay
  - Remaining reconstructed particles in the event form the hadronic system “X”
  - Additional experimental challenge due to unspecified hadronic “X” system
- Primary experimental challenge is modelling/ characterizing backgrounds:
  - B→Xlv (l=e,μ)decays
  - Generic $B\bar{B}$ events with mis-reconstruction
  - Continuum $q\bar{q}$ events

$$R(X) = \frac{\mathcal{B}(B \to X\tau\nu_\tau)}{\mathcal{B}(B \to X\ell\nu_\ell)}$$

$$e : p_T/p_{\rm lab} > 0.3\,\text{GeV}/0.5\,\text{GeV}$$
$$\mu : p_T/p_{\rm lab} > 0.4\,\text{GeV}/0.7\,\text{GeV}$$

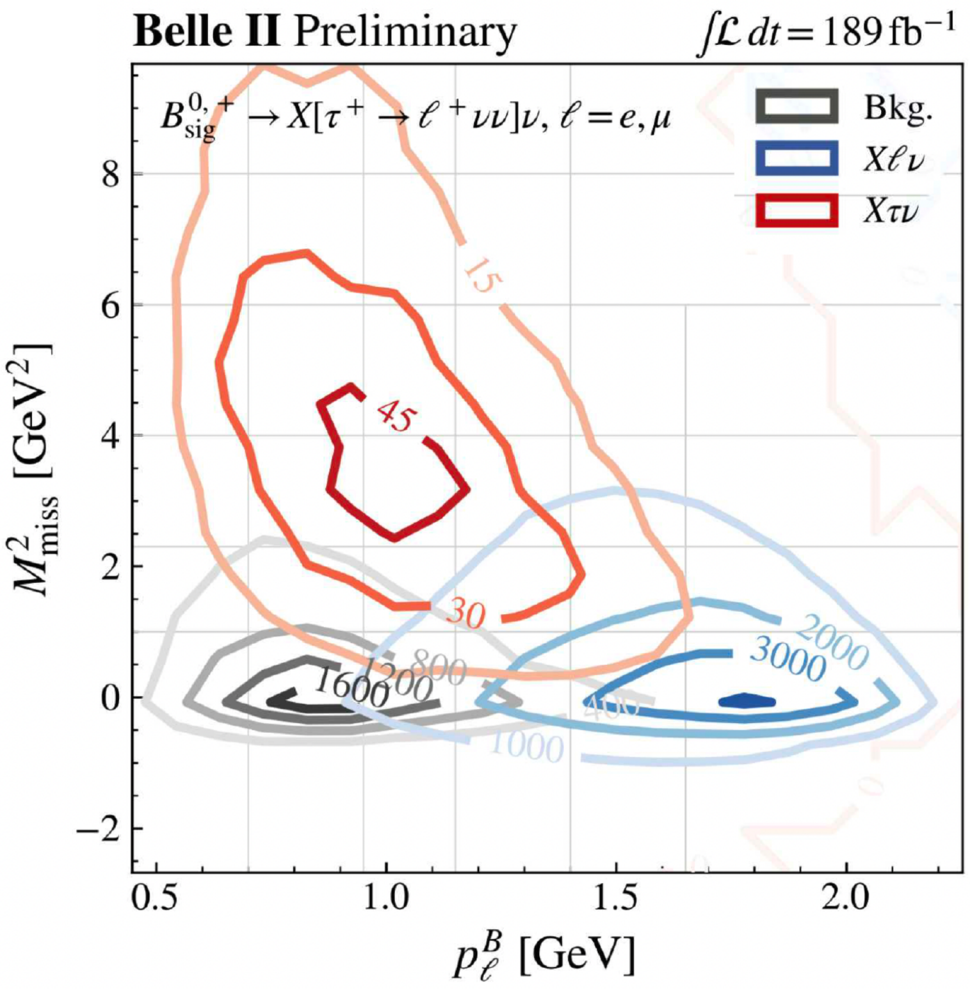
To reject misidentifed lepton



*Use a **data-driven corrections** for the “**not well-known**” stuff…*

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

- Signal determined from 2D distribution of p_l^B vs M_{miss}^2
- Data-driven X$\ell\nu$ modelling and reweighting using M_X distribution in $p_l^B > 1.4\ GeV$ sideband region
- Systematics dominated by data-driven corrections to background and signal modelling



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

Phys. Rev. Lett.132.211804 (2024)

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

$$R(X_{\tau/e}) = 0.232 \pm 0.020(\text{stat}) \pm 0.037(\text{syst}),$$
$$R(X_{\tau/\mu}) = 0.222 \pm 0.027(\text{stat}) \pm 0.050(\text{syst}),$$

Combined

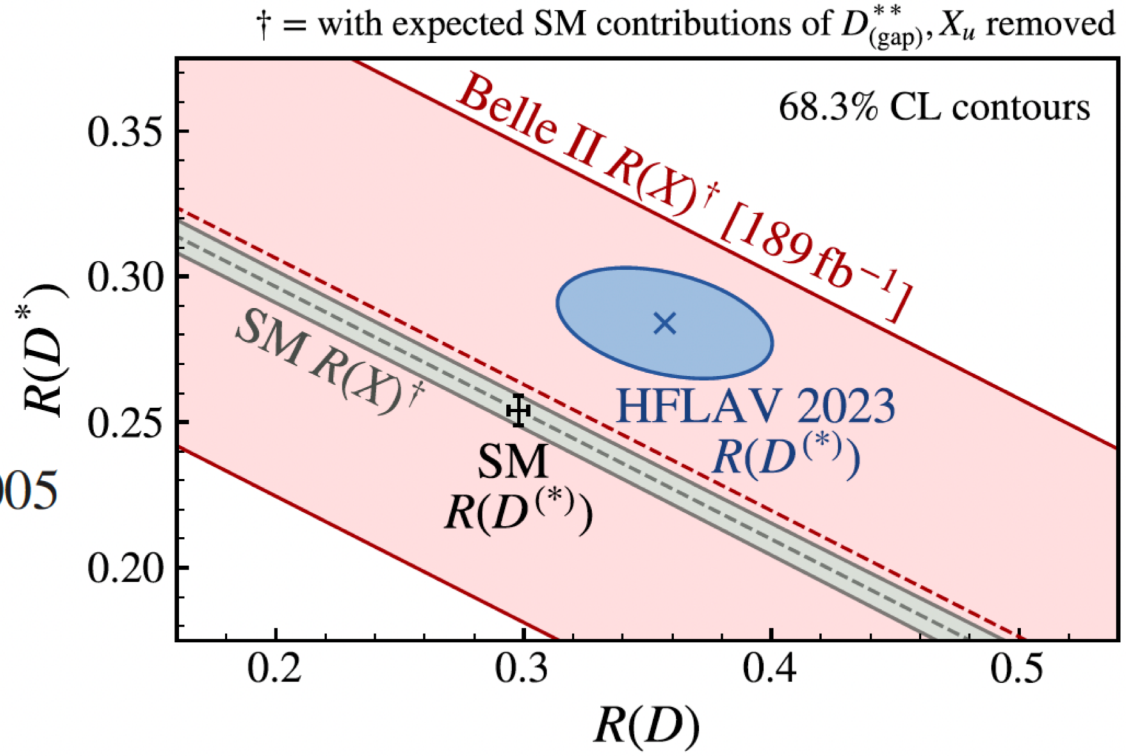
$$R(X_{\tau/\ell}) = 0.228 \pm 0.016(\text{stat}) \pm 0.036(\text{syst})$$

Average of SM expectation: 0.223 ± 0.005

PRD 105, 073009 (2022)
JHEP 11 007 (2022)

Limited by systematics, even with smallish data set

189 fb^{-1} collected at 2019 and 2021

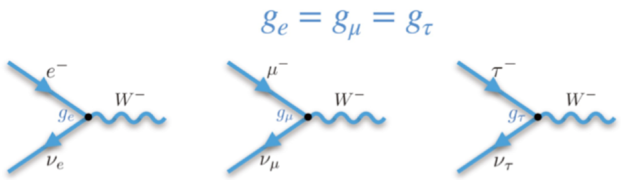


Consistent with SM predictions!

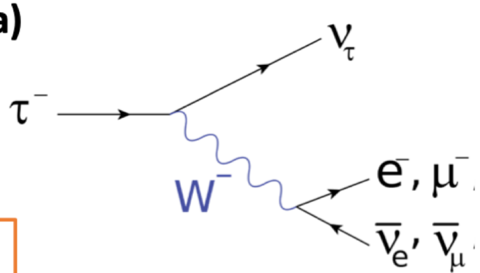
Main sources of syst. uncertainties: $X_c\ell\nu$ M_X shape: 7.1%, $\mathcal{B}(B \to X\ell\nu)$:7.7%, $X_c\tau(\ell)\nu$ form factors: 7.8%

Using τ to test Lepton Flavor Universality

Lepton Flavor Universality is an intrinsic and accidental property or symmetry of the SM: **couplings of EW boson to leptons are flavor-independent and the only difference between leptons is their mass (Yukawa)**



In τ decays, testing LFU symmetry is in principle very simple: compare the rates of $\tau \to \mu\nu\nu$ vs $\tau \to e\nu\nu$



$$R_\mu = \frac{BF[\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau]}{BF[\tau^- \to e^- \bar{\nu}_e \nu_\tau]}$$

Slightly smaller than 1 in the SM due to the $e - \mu$ mass difference ($R_\mu^{SM} = 0.9726$)

$$\left(\frac{g_\mu}{g_e}\right)_\tau = \sqrt{\frac{BF[\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau]}{BF[\tau^- \to e^- \bar{\nu}_e \nu_\tau]} \frac{f(m_e^2/m_\tau^2)}{f(m_\mu^2/m_\tau^2)}}$$

$$f(x) = -8x + 8x^3 - x^4 - 12x^2 \log x$$

Exactly 1 in the SM

NP could enter in different ways:
- LFUV charged currents
- LFV neutral currents [ex. Soni et al., $L_\mu - L_\tau$ Z' Phys. Lett. B 2016 09 046]

Measurement by BaBar [PRL 105 051602]:

$R_\mu = 0.9796 \pm 0.0016_{stat} \pm 0.0036_{sys}$

$\left(\frac{g_\mu}{g_e}\right)_\tau = 1.0036 \pm 0.0020$

Test of LFU in leptonic τ decays at Belle II: 1x1 event topology

We use the 1x1 event topology.

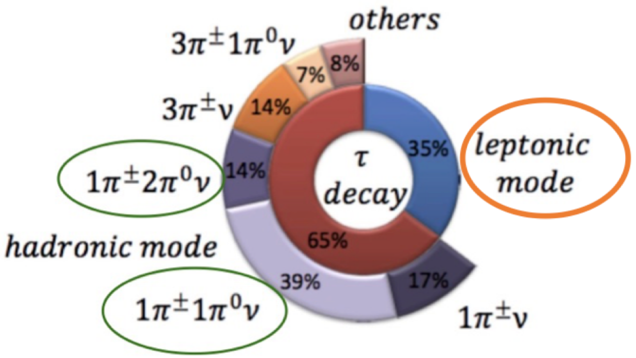
The "tag side" is a 1-prong (i.e. one charged track) τ decay containing one charged hadron ($\pi^{\pm}$) and at least a π^0 (i.e. $\boldsymbol{\tau^+ \to \pi^+\pi^0\overline{\upsilon_\tau}, \tau^+ \to \pi^+\pi^0\pi^0\overline{\upsilon_\tau}}$ and C.C.). The signal side is a fully leptonic tau decay (i.e. $\boldsymbol{\tau^- \to e^-\overline{\upsilon_e}\upsilon_\tau, \tau^- \to \mu^-\overline{\upsilon_\mu}\upsilon_\tau}$, and C.C.)

- Large BFs, low backgrounds and high trigger efficiency

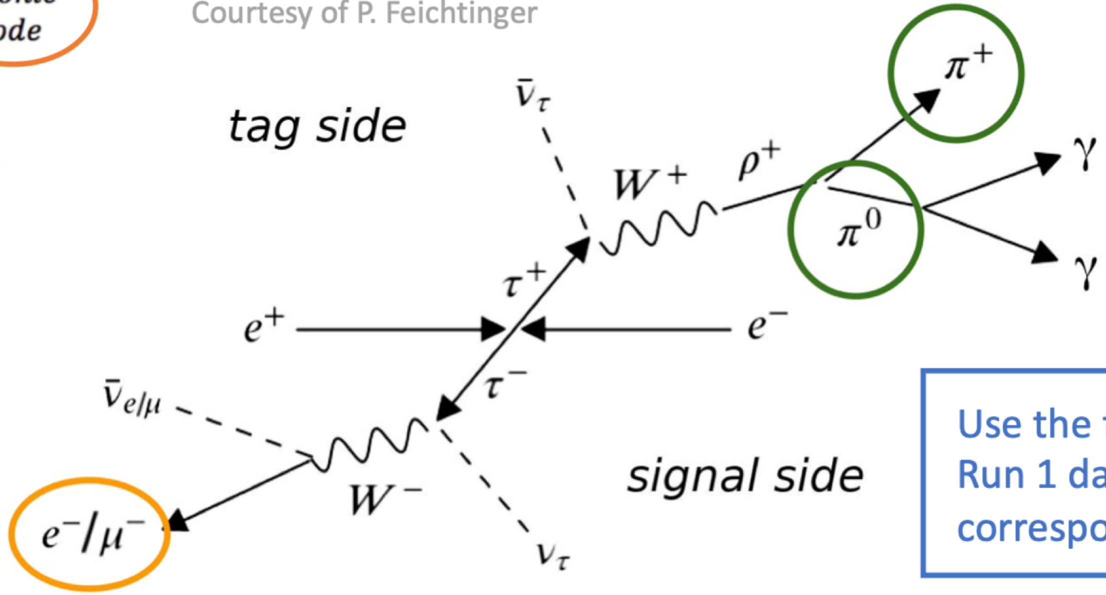
Tag side pre-selection

✓ 1 charged track with $\frac{E_{cluster}}{p} < 0.8$

✓ $N(\pi^0) > 0$



Courtesy of P. Feichtinger



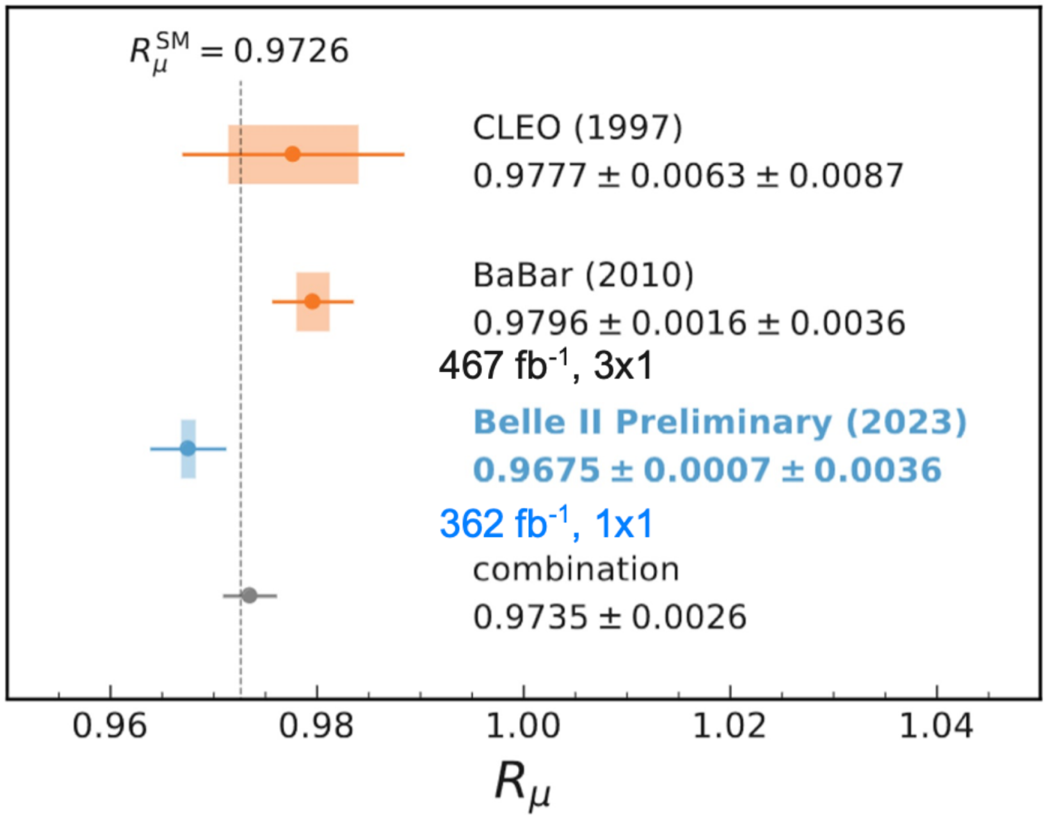
Signal side pre-selection

✓ 1 charged track identified (PID) as μ or e.

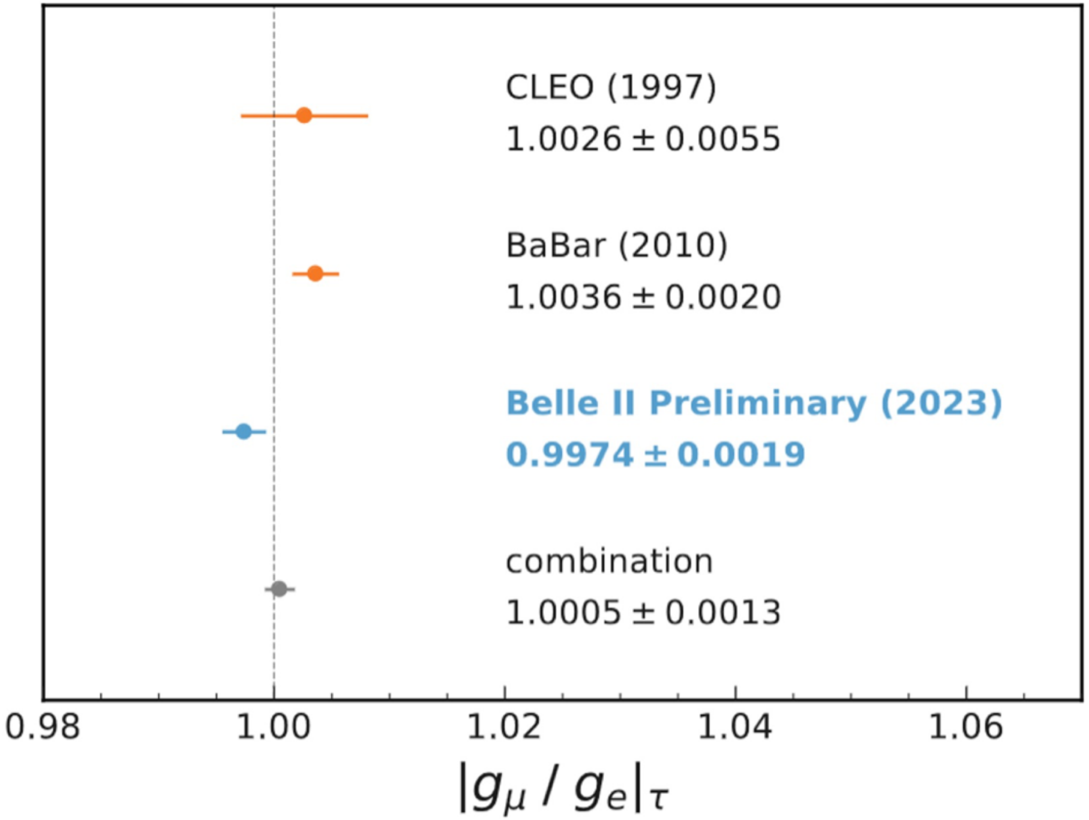
Use the full "on resonance" Run 1 data (2019-2022), corresponding to 362 fb^{-1}

Test of LFU in leptonic τ decays at Belle II: results

$$R_\mu = \frac{BF[\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau]}{BF[\tau^- \to e^- \bar{\nu}_e \nu_\tau]}$$



$$\left(\frac{g_\mu}{g_e}\right)_\tau = \sqrt{\frac{BF[\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau]}{BF[\tau^- \to e^- \bar{\nu}_e \nu_\tau]} \frac{f(m_e^2/m_\tau^2)}{f(m_\mu^2/m_\tau^2)}}$$

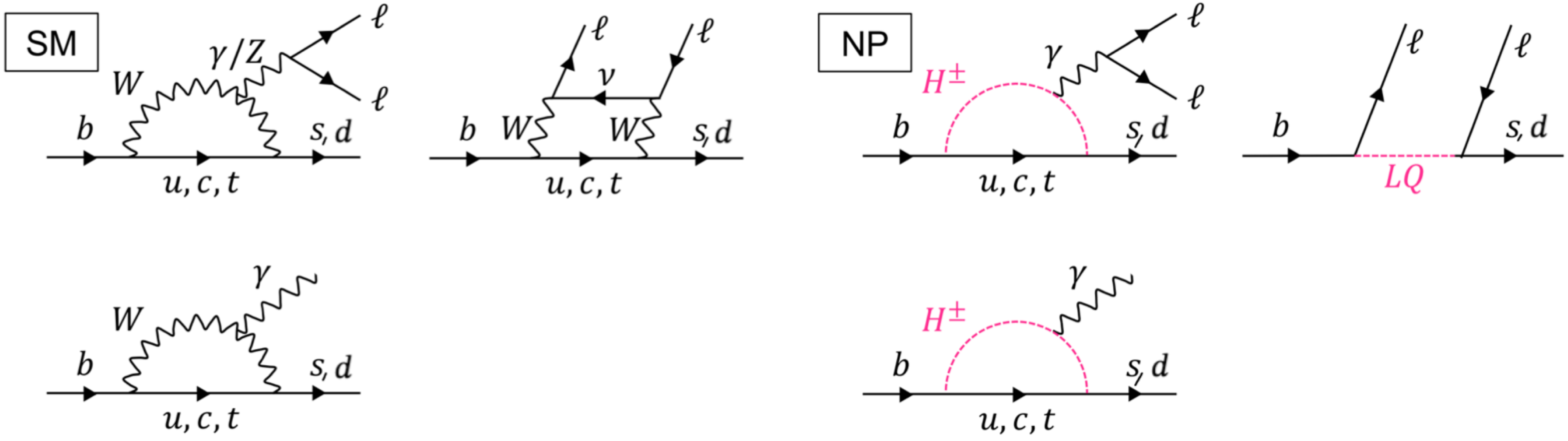


World's most precise test of LFU in τ decays and most precise determination of R_μ and $|g_\mu/g_e|$

Submitted to JHEP, see [ArXiv 2405.14625]

Radiative and Electroweak Penguin decays of B mesons

Radiative and Electroweak Penguin decays of B mesons



- Flavor-changing-neutral-current (**FCNC**) occurs only by loop diagrams in the SM
  - New physics (NP) appearing in the loop can change the variables like branching ratio, CP asymmetry, and isospin asymmetry
  - Electroweak Penguin (EWP) is one of such loop diagrams
- **FCNC of B meson is relatively large thanks to V_{tb}~1**
  → Highly sensitive to NP
- One of the main targets of B factory experiments

$B^+ \to K^+\nu\bar{\nu}$ decays

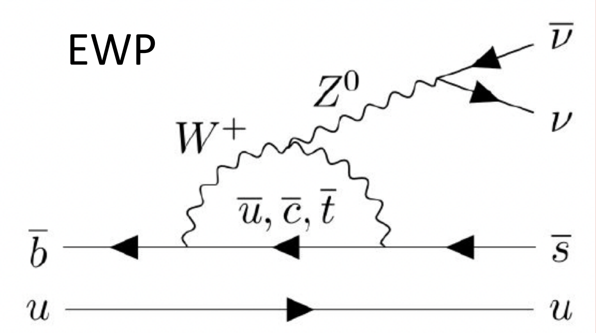
- $B^+ \to K^+\nu\bar{\nu}$ is a challenging ⇒ single charged track in the final state
- $\mathcal{B}$(SM) = (5.58 ± 0.37) x 10^{-5} [PRD 107, 014511]
- New physics could alter the rate (also angular observables for $B \to K^*\nu\bar{\nu}$)

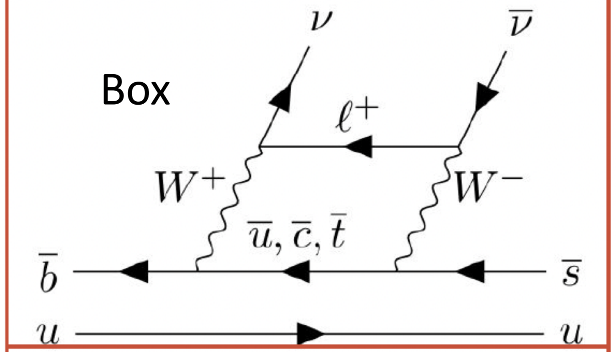
Advantages at Belle II:

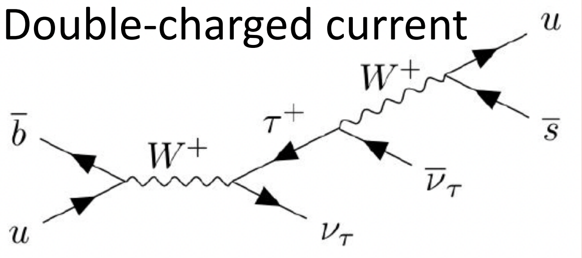
- Constraints from well-known initial state kinematics;
- Lower average multiplicity at the Υ(4S) compared to hadronic collisions

NP scenarios:

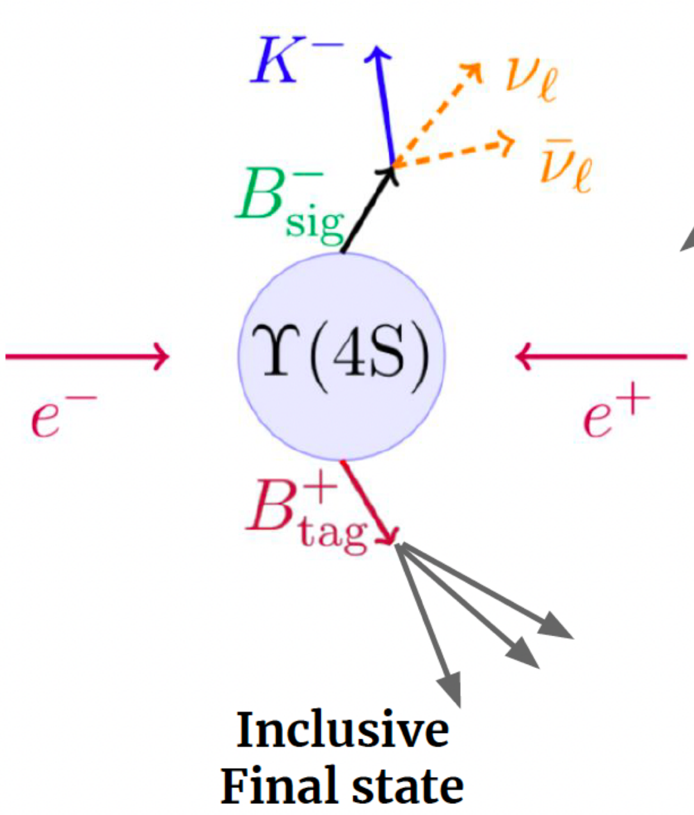
- **Light** : axions [PRD 102, 015023 (2020)],
- dark scalars [PRD 101, 095006 (2020)],
- axion-like particles [JHEP 04 (2023) 131]
- **Heavy** : Z' [PL B 821 (2021) 136607],
- leptoquarks [PRD 98, 055003 (2018)]







B-tagging algorithm

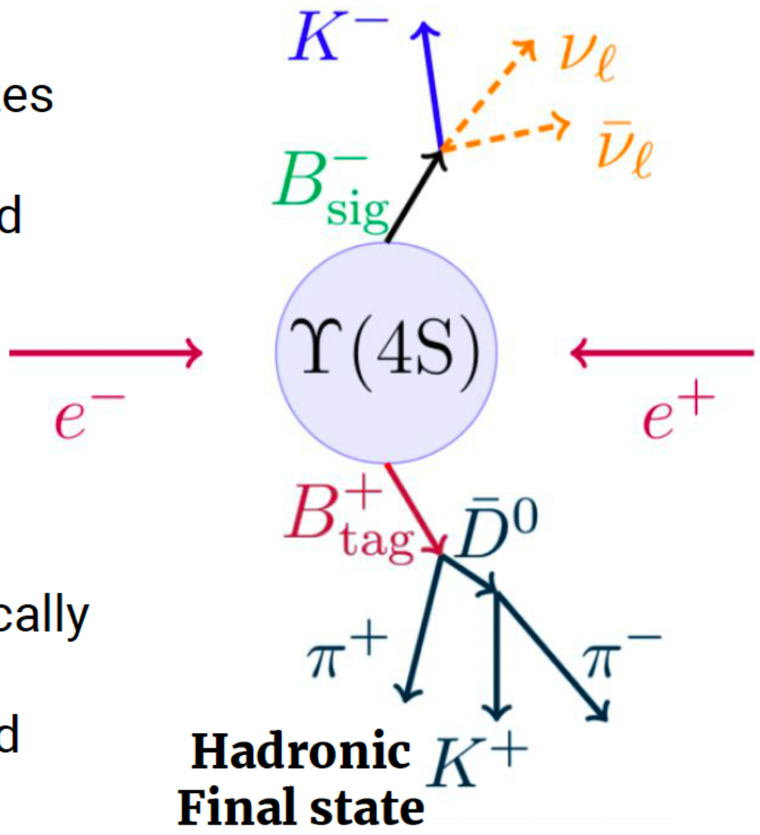


Inclusive tag analysis (ITA)

- Select first signal kaon that minimizes q^2_{rec} (computed as K^+ recoil)
- Nested BDT to suppress background
- Fit q^2_{rec} and BDT output

Hadronic tag analysis (HTA)

- Select first tag B decaying hadronically [Comput Softw Big Sci 3, 6 (2019)]
- Single BDT to suppress background
- Fit BDT output



signal efficiency = 8%; purity = 0.9%

signal efficiency = 0.4%; purity = 3.5%

$B^+ \to K^+ \nu\bar{\nu}$ signal extraction

Variables

- η: a signal classifier* remapped so that signal is **flat**
- q^2_{rec}: inferred neutrino mass squared

ITA:

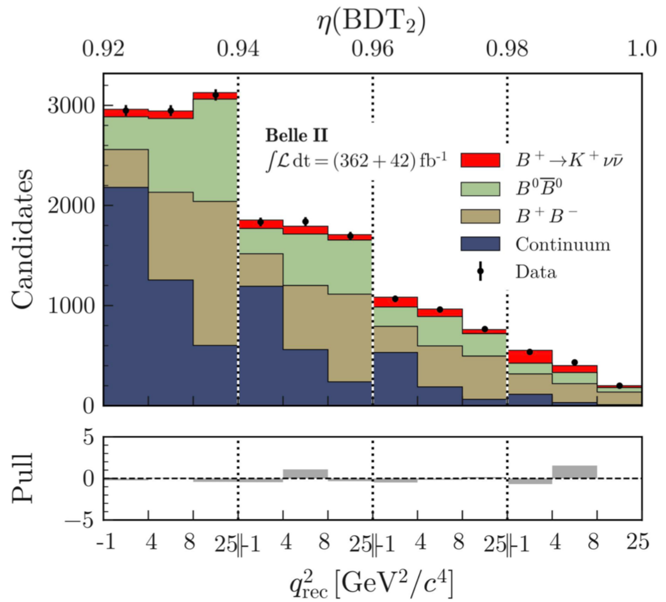
- Simultaneous on-/off-resonance fit
- (4 bins in η)×(3 bins in q^2_{rec})

HTA:

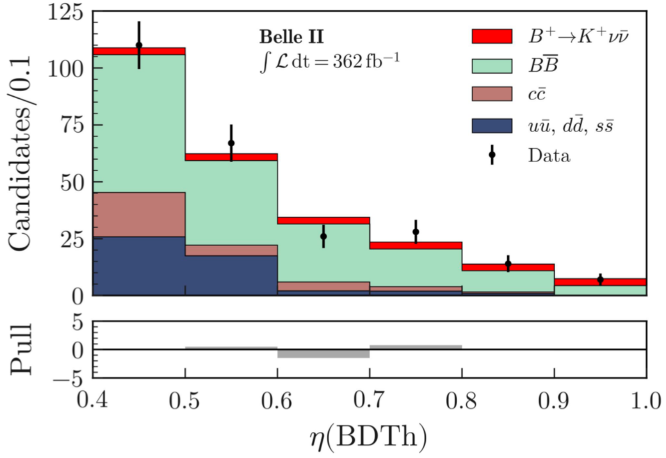
- Fit to six bins of signal classifier η(BDTh)

(the key is extensive controls/validations)

ITA



HTA



Evidence for $B^+ \to K^+ \nu\bar{\nu}$ decays

Combined ITA and HTA:

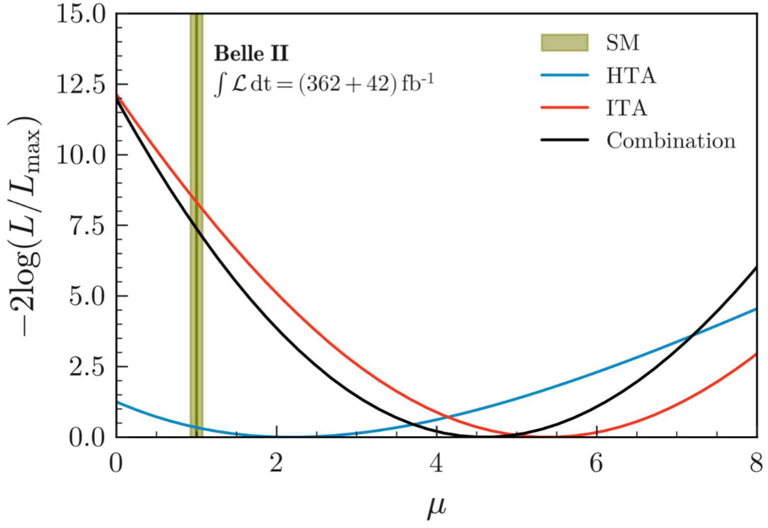
- Signal strength ($\mu_{SM, short-range} \equiv 1$):

$$\mu = 4.6 \pm 1.0(\text{stat}) \pm 0.9(\text{syst}) = 4.6 \pm 1.3$$

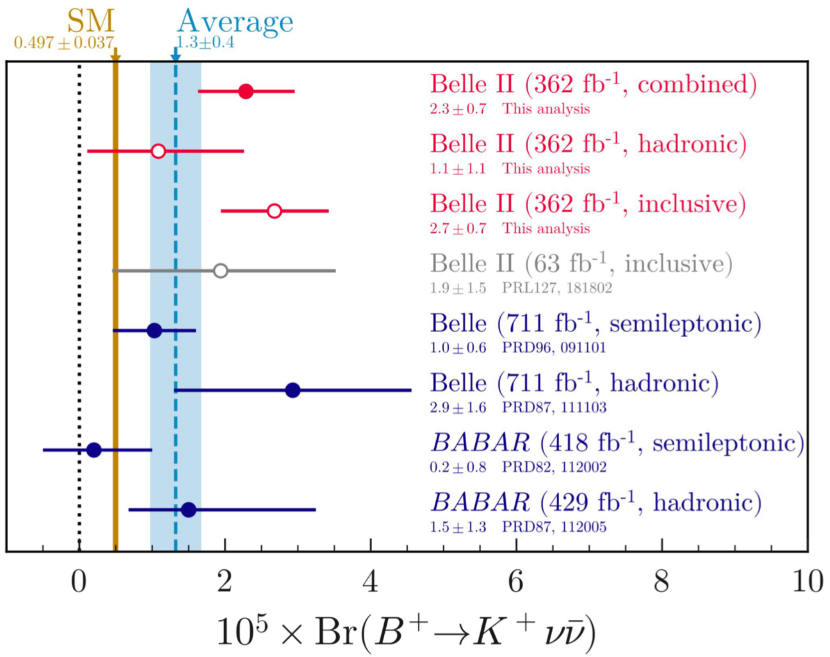
- Branching fraction:

$$\left[2.3 \pm 0.5(\text{stat})^{+0.5}_{-0.4}(\text{syst})\right] \times 10^{-5} = (2.3 \pm 0.7) \times 10^{-5}$$

ITA and HTA results are **compatible**, **independent**, and both approximately equally limited by stats and systematics



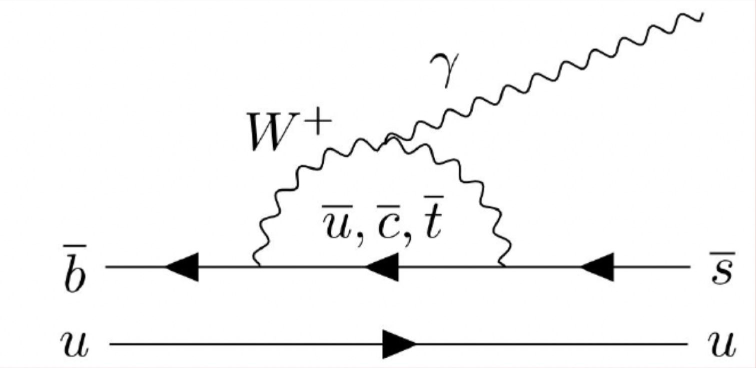
- First evidence for the decay $B^+ \to K^+ \nu\bar{\nu}$ (3.5 σ)
- BF is 2.7σ away from SM prediction.
- New Inclusive method established



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

First measurement of B->K*(892)γ at Belle II

Flavour changing neutral current decays sensitive to new physics
First observed FCNC decay [PRL 71 (1993) 674]
CP (A_{CP}) and isospin (Δ_{+0}) asymmetries are theoretically clean thanks to form factor cancellations
Asymmetries are ideal for BSM searches [PRD 88 (2013) 094004] [PRL 106 (2011) 141801]
Belle measurement found evidence of isospin asymmetry at 3.1σ [PRL 119 (2017) 191802]



$$A_{CP} = \frac{\Gamma(\bar{B} \to \overline{K^*}\gamma) - \Gamma(B \to K^*\gamma)}{\Gamma(\bar{B} \to \overline{K^*}\gamma) + \Gamma(B \to K^*\gamma)}$$

SM prediction is small (~1%)

$$\Delta A_{CP} = A_{CP}(B^0 \to K^{*0}\gamma) - A_{CP}(B^+ \to K^{*+}\gamma)$$

$$\Delta_{+0} = \frac{\Gamma(B^0 \to K^{*0}\gamma) - (B^+ \to K^{*+}\gamma)}{\Gamma(B^0 \to K^{*0}\gamma) + (B^+ \to K^{*+}\gamma)}$$

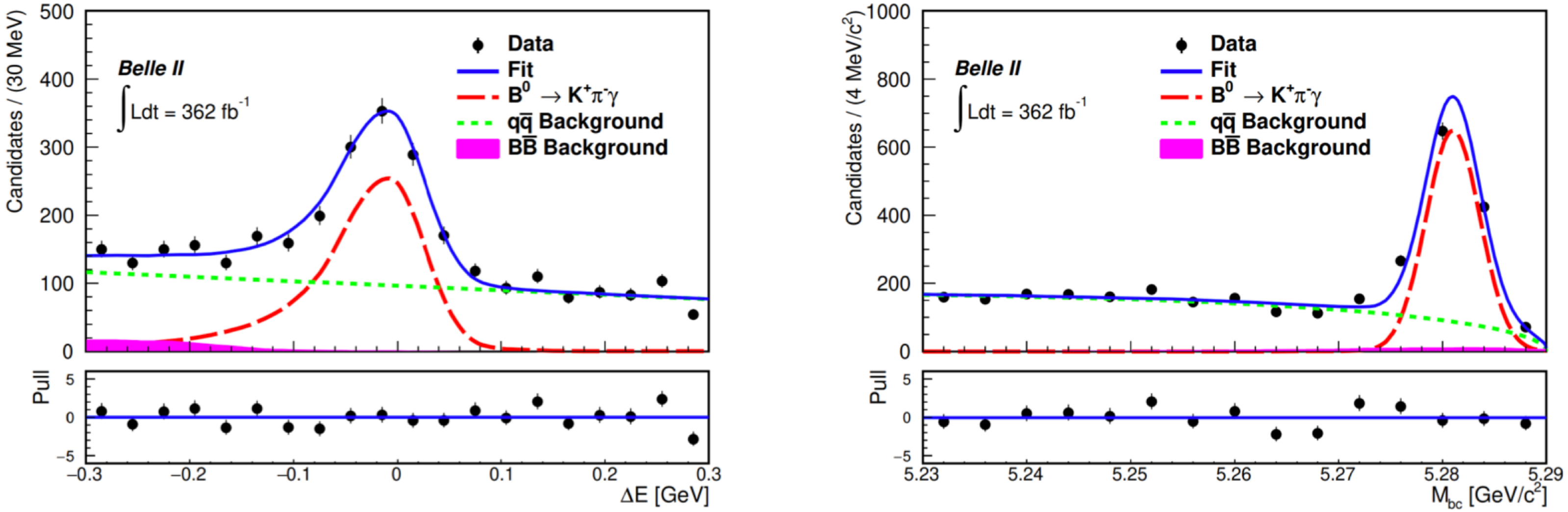
SM prediction: 4.9 ± 2.6% [PRD 88 (2013) 094004]

B->K*(892)γ: Analysis

Signal:

- $B^0 \to K^{*0}[\to K^+\pi^-]\gamma$
- $B^0 \to K^{*0}[\to K_S^0\pi^0]\gamma$
- $B^+ \to K^{*+}[\to K^+\pi^0]\gamma$
- $B^+ \to K^{*+}[\to K_S^0\pi^+]\gamma$

- 2D fit on Belle II (362 fb^{-1}) data
  - M_{bc}, ΔE



B->K*(892)γ : Results

$$\mathcal{B}[B^0 \to K^{*0}\gamma] = (4.16 \pm 0.10 \pm 0.11) \times 10^{-5},$$

$$\mathcal{B}[B^+ \to K^{*+}\gamma] = (4.04 \pm 0.13 \pm 0.13) \times 10^{-5},$$

$$\mathcal{A}_{CP}[B^0 \to K^{*0}\gamma] = (-3.2 \pm 2.4 \pm 0.4)\%,$$

$$\mathcal{A}_{CP}[B^+ \to K^{*+}\gamma] = (-1.0 \pm 3.0 \pm 0.6)\%,$$

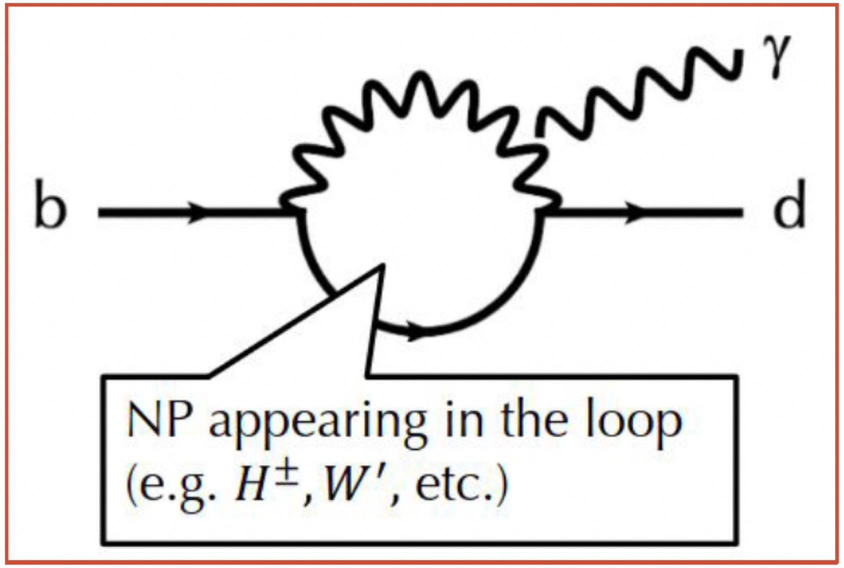
$$\Delta\mathcal{A}_{CP} = (2.2 \pm 3.8 \pm 0.7)\%, \qquad \Delta_{0+} = (5.1 \pm 2.0 \pm 1.0 \pm 1.1)\%$$

- Consistent with World average and SM
- Asymmetries are statistically limited
- Similar sensitivity to Belle result despite half the data
  Δ_{0+}= 6.2 ± 1.5 (stat) ± 0.6 (sys) ± 1.2 (f_{+-}/f_{00}) [PRL 119, 191802 (2017)]
  (Thanks to improved K^0_S efficiency, continuum suppression, and improved fit model)

Paper in preparation

Exclusive measurement of B→$\rho\gamma$ at Belle and Belle II

- Flavor changing neutral current with b → d transition
- Independent search for NP [PRD 88 (2013) 094004]
- SM branching fraction suppressed by |Vtd /Vts | ~ 0.04 with respect to B->K*(892)γ
- The first "charmless" study with Belle and Belle II joint data
- Earlier results from Belle [Phys. Rev. Lett. 101, 111801] and BaBar [Phys. Rev. D 78, 112001].



$$\mathcal{A}_{CP} = \frac{\Gamma(\overline{B} \to \overline{\rho}\gamma) - \Gamma(B \to \rho\gamma)}{\Gamma(\overline{B} \to \overline{\rho}\gamma) + \Gamma(B \to \rho\gamma)}$$

$$\mathcal{A}_I = \frac{2\Gamma(B^{0/\overline{0}} \to \rho^0\gamma) - \Gamma(B^{+/-} \to \rho^{+/-}\gamma)}{2\Gamma(B^{0/\overline{0}} \to \rho^0\gamma) + \Gamma(B^{+/-} \to \rho^{+/-}\gamma)}$$

$A_I^{W.A.} = (30^{+16}_{-13})\%$ to date

SM prediction: 5.2 ± 2.8% [PRD 88 (2013) 094004]

Current world average deviates by 2σ from SM

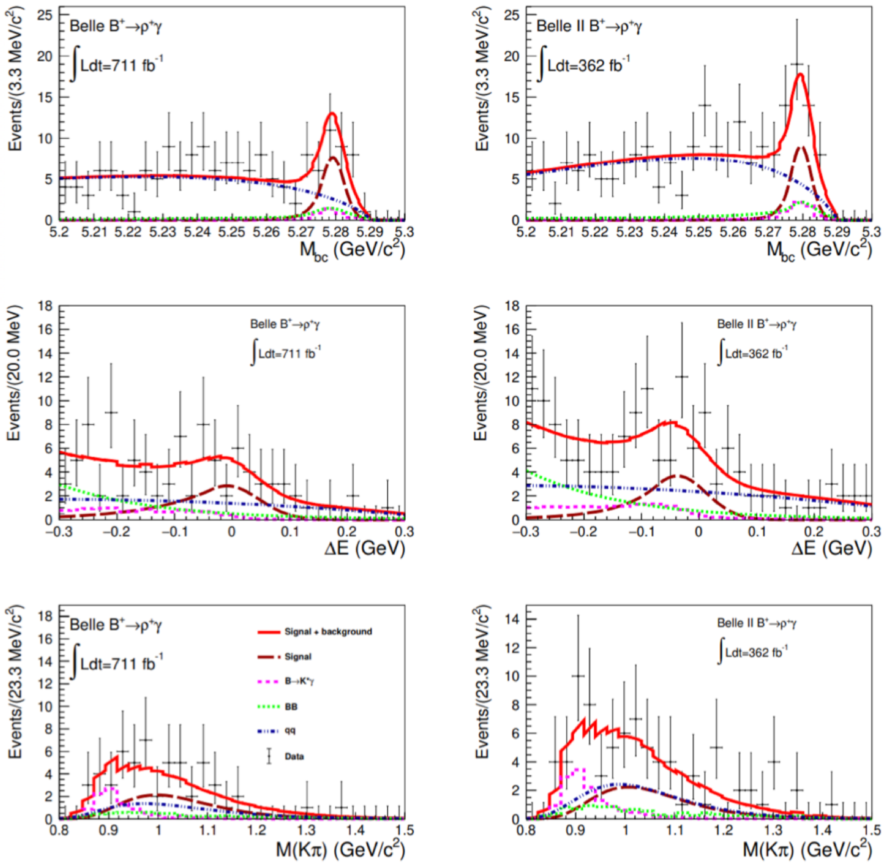
B→ργ : Analysis

- Analysis based on Belle (711 fb^{-1}) + Belle II (362 fb^{-1}) data
- Reconstruct $\rho^0 \to \pi^+\pi^-$ and $\rho^+ \to \pi^+\pi^0$, combine with prompt photon
- Define $M_{K\pi}$ as the invariant mass calculated assuming π^+ is K^+
- The $M_{K\pi}$ helps separate $K^*\gamma$ background better compared to $M_{\pi\pi}$
- Dedicated BDTs to suppress continuum, $\pi \to \gamma\gamma$, and $\eta \to \gamma\gamma$ decays

Fit Strategy

- Perform Belle+Belle II simultaneous 3D fit of M_{bc}, ΔE and $M_{K\pi}$

- **Control sample study**
- Employed $B \to K^{*0} [K^-\pi^+]\gamma$ to calibrate the BDTs (continuum, $\pi \to \gamma\gamma$, and $\eta \to \gamma\gamma$) and signal PDF modelling



arXiv:2407.08984, submitted to PRD

$B \to \rho\gamma$: Results

Charge Parity Asymmetry:

$$\mathcal{A}_{CP} = \frac{\Gamma(\overline{B} \to \bar{\rho}\gamma) - \Gamma(B \to \rho\gamma)}{\Gamma(\overline{B} \to \bar{\rho}\gamma) + \Gamma(B \to \rho\gamma)}$$

Isospin Asymmetry (CP average):

$$\mathcal{A}_I = \frac{2\Gamma(B^{0/\bar{0}} \to \rho^0\gamma) - \Gamma(B^{+/-} \to \rho^{+/-}\gamma)}{2\Gamma(B^{0/\bar{0}} \to \rho^0\gamma) + \Gamma(B^{+/-} \to \rho^{+/-}\gamma)}$$

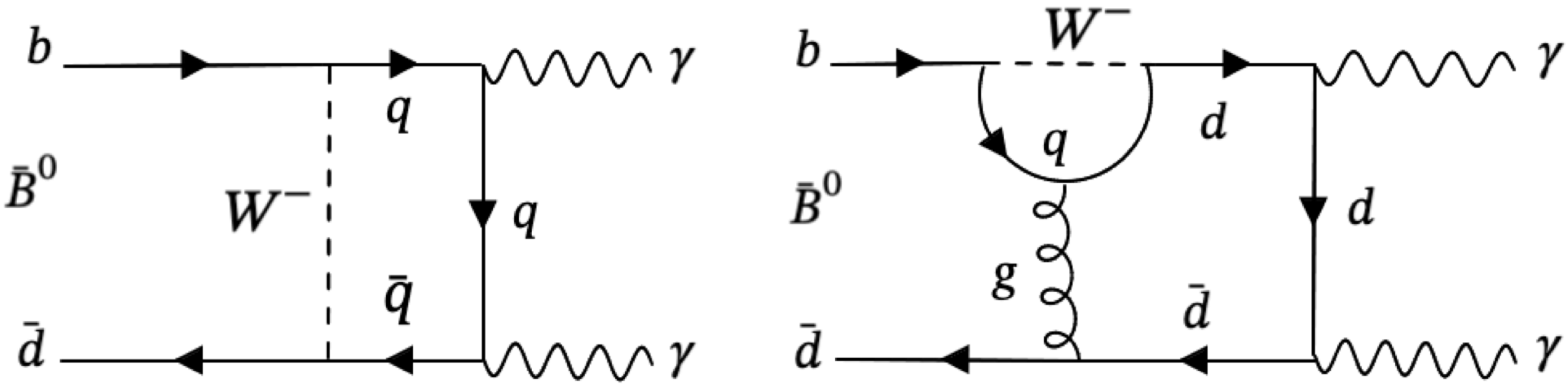
- Standard Model prediction: $A_I = (5.2 \pm 2.8)\%$
- World average of $A_I = (30^{+16}_{-13})\%$ – 2σ from Standard Model

arXiv:2407.08984, submitted to PRD

- Signal events:
  - 114 ± 12 $B^+ \to \rho^+\gamma$
  - 99 ± 12 $B^0 \to \rho^0\gamma$
- Branching fractions
  - $\mathbf{B}(B^+ \to \rho^+\gamma) = (13.1^{+2.0+1.3}_{-1.9-1.2}) \cdot 10^{-7}$
  - $\mathbf{B}(B^0 \to \rho^0\gamma) = (7.5^{+1.3+1.0}_{-1.3-0.8}) \cdot 10^{-7}$
- $\mathcal{A}_{CP} = (B^+ \to \rho^+\gamma) = (-8.2^{+15.2+1.6}_{-15.2-1.2})\%$
- $\mathcal{A}_I = (B \to \rho\gamma) = (10.9^{+11.2+7.8}_{-11.7-7.3})\%$
- Measured Asymmetries are consistent with Standard Model

World best precision is achieved
Independent NP search from $B \to K{*}\gamma$

Search for B→$\gamma\gamma$ at Belle and Belle II



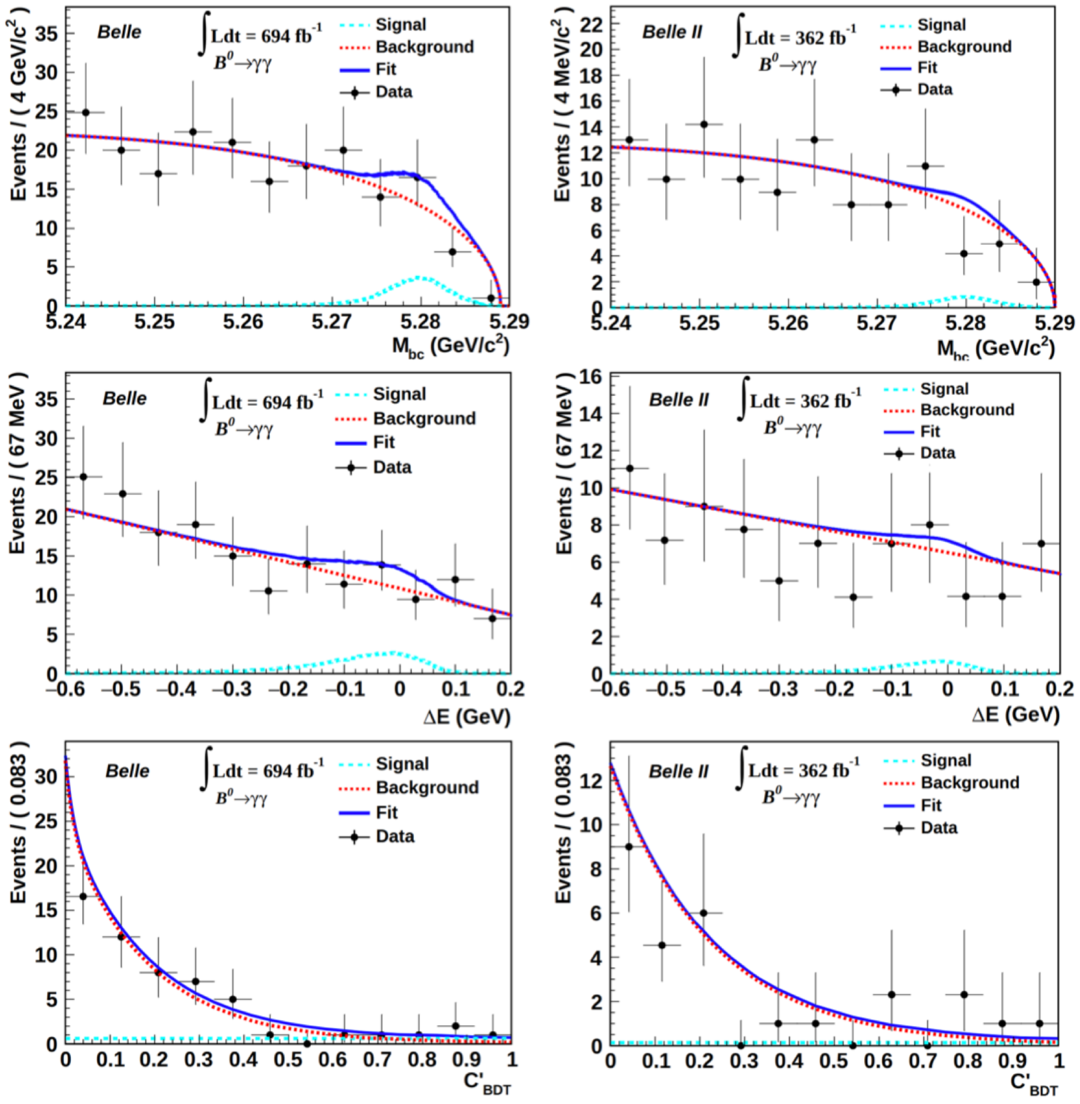
- Decay in SM through loop diagram with W^- emitted and absorbed
- Long distance penguin contribution
- Suppressed by factor $|V_{td}|/|V_{ts}| \approx 0.04$ compared to $B_s \to \gamma\gamma$
- SM prediction: $\mathcal{B}(B^0 \to \gamma\gamma) = (1.4^{+1.4}_{-0.8}) \cdot 10^{-8}$ [JHEP12(2020)169]

B→ $\gamma\gamma$: Results

arXiv:2405.19734, Accepted by PRD

- Simultaneous fit of Belle (694 fb^{-1}) + Belle II (362 fb^{-1}) data
  - M_{bc} – beam constrained mass $\sqrt{(\text{Beam energy})^2 - (\text{Momentum of } B^0)^2}$
  - ΔE – energy difference $(\text{Energy of } B^0) - (\text{Beam energy})$
  - BDT trained on π^0 and η dominated events
- Signal events: $11.0^{+6.5}_{-5.5}$, 2.5σ significance
- $\mathcal{B}^{UL}(B^0 \to \gamma\gamma) < 6.4 \cdot 10^{-8}$, 90% CL
- $\mathcal{B}^{UL}_{SM}(B^0 \to \gamma\gamma) < 4.4 \cdot 10^{-8}$, 90% CL

Upper limit 5 times more restrictive than previous (BaBar) measurement [PhysRevD(2011)83]



Summary

- Test of Lepton Flavour Universality
  - ✓ Lepton Flavour Universality Violation provides powerful tools for exploration of physics beyond standard model
  - ✓ Experimentally challenging analyses, many channels tried
  - ✓ Common effort with theory to improve the interpretation of the results and the SM expectations
- Reported the EWP analyses in Belle and Belle II
  - ✓ Some studies use Belle + Belle II data to achieve the current best precision
  - ✓ No evidence for new physics so far
- Many world-leading results
  - ✓ First inclusive R(X) at Belle II
  - ✓ 3.5σ evidence for $B^+ \to K^+ \nu\bar{\nu}$
  - ✓ World best precision for $B \to \rho\gamma$, $B \to \gamma\gamma$ by Belle + Belle II
  - ✓ Most of them are unique to Belle / Belle II for the final states with neutral particles or missing energy
- Many new results, and more analyses ongoing, just scratching the surface

Thank you for your attention

Data-driven corrections

The ***invariant mass of the X system*** controls the **physics** we know the least about

Control variable

$$M_X^2 = \begin{pmatrix} E_X \\ \overrightarrow{p_X} \end{pmatrix}^2$$

Extraction variable

$$M_{\text{miss}}^2 = \left[\begin{pmatrix} E_{\text{CMS}} \\ \overrightarrow{p_{\text{CMS}}} \end{pmatrix} - \begin{pmatrix} E_{\text{CMS}}/2 \\ -\overrightarrow{p_{B_{\text{tag}}}} \end{pmatrix} - \begin{pmatrix} E_\ell \\ \overrightarrow{p_\ell} \end{pmatrix} - \begin{pmatrix} E_X \\ \overrightarrow{p_X} \end{pmatrix} \right]^2$$

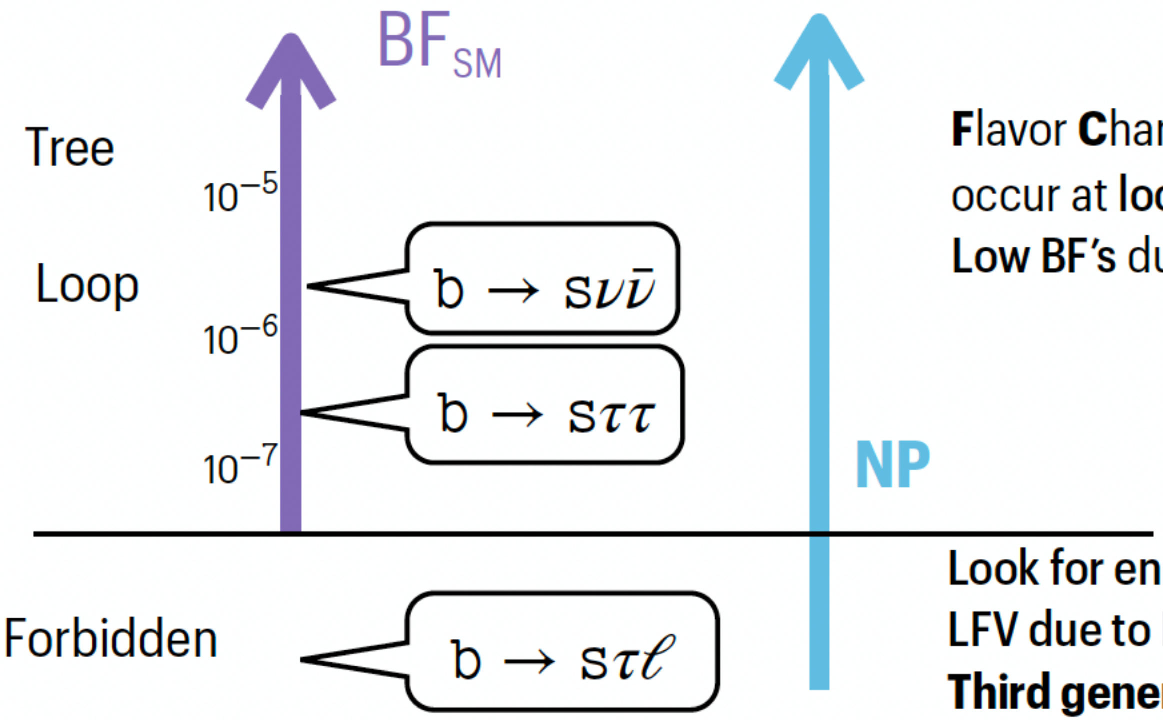
Independent test variable

$$q^2 = \left[\begin{pmatrix} E_{\text{CMS}}/2 \\ -\overrightarrow{p_{B_{\text{tag}}}} \end{pmatrix} - \begin{pmatrix} E_X \\ \overrightarrow{p_X} \end{pmatrix} \right]^2$$

TOTAL INTEGRATED LUMINOSITY FOR GOOD RUNS

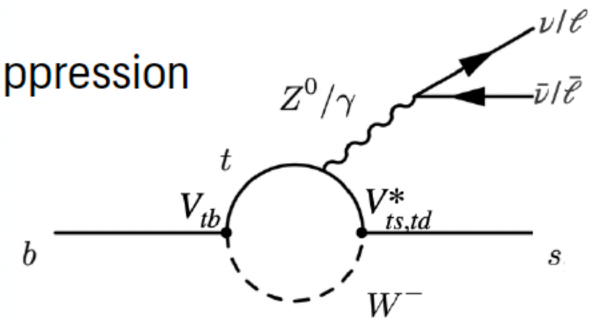
- Total integrated luminosity: **424 fb-1**
- Total integrated luminosity at the Y(4S) resonance: **363 fb-1**
- Total integrated luminosity below Y(4S) resonance: **42 fb-1**
- Total integrated luminosity above Y(4S) resonance: **19 fb-1**

modeled using PYTHIA. The signal (normalization) model includes the following exclusive decays, with charge conjugation implied throughout: $B \to D\tau(\ell)\nu$, $B \to D^*\tau(\ell)\nu$, and $B \to D^{**}\tau(\ell)\nu$, where D^{**} collectively indicates the excited charmed states D_0^*, D_1', D_1, and D_2^*, whose masses and widths are taken from Ref. [35]. The $B \to D^{(*)}\tau(\ell)\nu$ decays are modeled with the BLPRXP form-factor parametrization [36]. The modeling of $B \to D^{**}\tau(\ell)\nu$ decays is based on the BLR model [37,38]. Semileptonic B decays into the nonresonant final states $D^{(*)}\pi\pi\tau(\ell)\nu$ and $D^{(*)}\eta\tau(\ell)\nu$ are used to fill the difference between the sum of individual branching ratios of exclusive decays, $B \to D^{(*,**)}\tau(\ell)\nu$, and the total semileptonic B decay widths. These "gap modes" are included in dedicated simulated samples that use intermediate, broad D^{**} resonances and are modeled with BLR. We take the total width for decays to light leptons from Ref. [35]; the widths for



Flavor **C**hanging **N**eutral **C**urrents **(FCNC)** $b \to s$ occur at **loop level** in the **SM**

Low BF's due to CKM and GIM suppression



Look for enhancements in FCNC and LFV due to NP contributions

Third generation coupling