Hot Topic in Flavour at the B Factories

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On behalf of the Belle and Belle II Collaborations

9th Workshop on Theory, Phenomenology and Experiments in Flavor Physics
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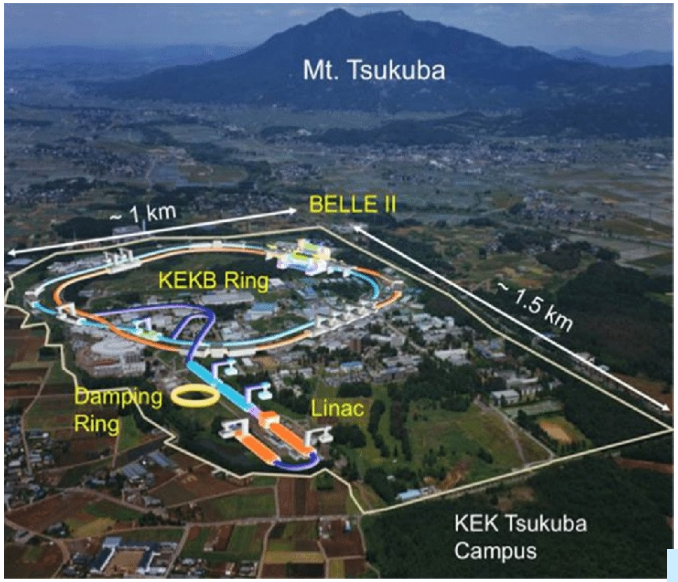
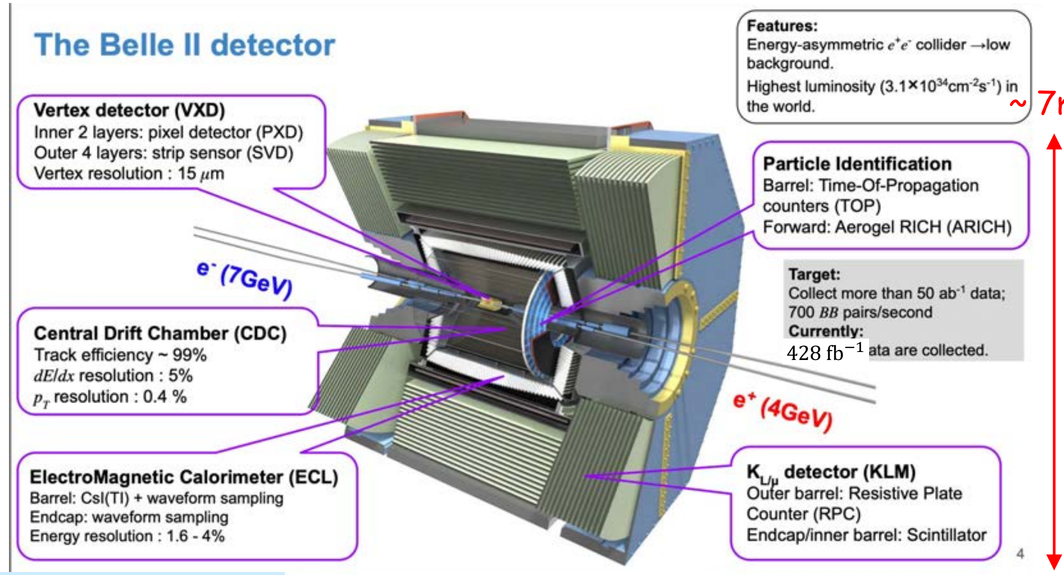
Belle and Belle II experiments





Belle II TDR: arXiv:1011.0352

~ 7.5m

$\beta\gamma = 0.28$

- Asymmetric $e^+e^- \to \Upsilon(4S) \to B\bar{B}$ with production cross section $\sim 1.1nb$
  - ✓ Belle → Belle II: $e^+(3.5\text{ GeV})e^-(8\text{ GeV}) \to e^+(4\text{ GeV})e^-(7\text{ GeV})$
- Belle (1999-2010): $1.4\ ab^{-1}$ with $711\ fb^{-1}$ at $\Upsilon(4S)$, $\mathcal{L}_{peak} = 2.1\times10^{34}cm^{-2}s^{-1}$
- Belle II collected $428\ fb^{-1}$ data for Run 1 with record $\mathcal{L}_{peak} = 4.7\times10^{34}cm^{-2}s^{-1}$
  - ✓ Restart data taking in 2024, Final goal: $50\ ab^{-1}$ data at $\mathcal{L}_{peak} = 6.5\times10^{35}cm^{-2}s^{-1}$
  - ✓ Improved detector performance and data analysis techniques

Outline of the talk

- This is not a review talk
  - ✓ Some selected recent results from Belle/Belle II
  - ✓ Focus on results sensitive to New Physics (NP)
  - ✓ Focus on measurements most sensitive at B factory

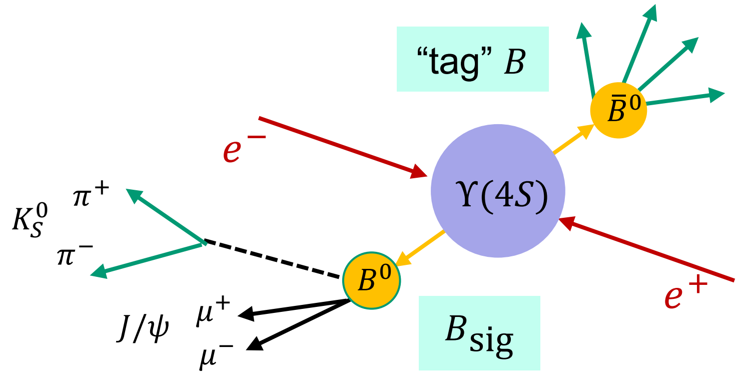
- Topics:
  - ✓ Measurements of CP Violation (CPV) in B decays
  - ✓ Rare and forbidden B, charm and Tau decays
  - ✓ Test of lepton flavor universality
  - ✓ No Dark Sector: see the talk by Martina Laurenza

- Avoid too much experimental details

- Comparison to previous results and outlook in the future

B Flavor tagging at Belle II

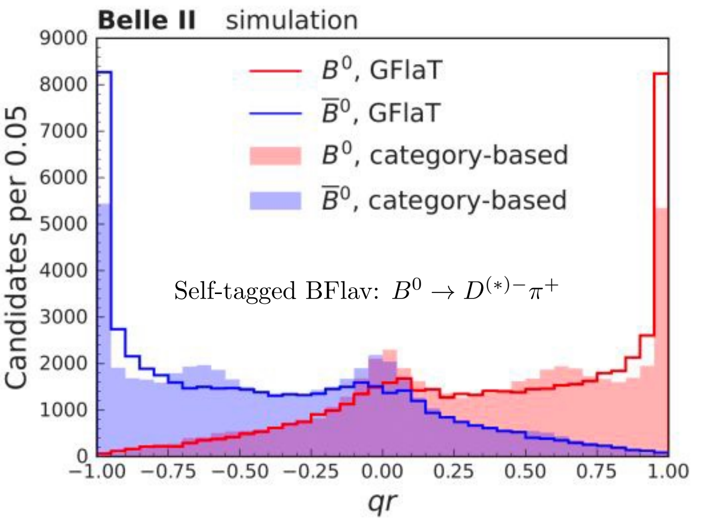
- B flavor tagging: Identify the flavor of the other B

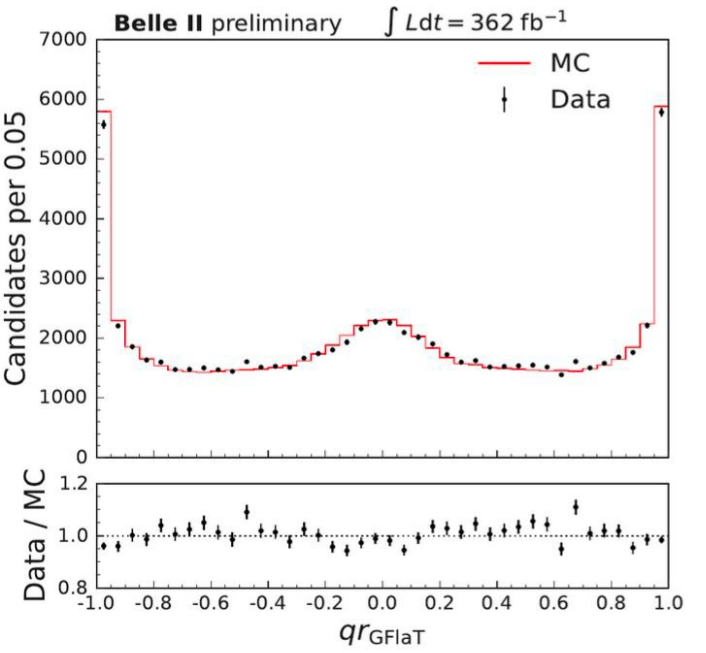


- Belle II initial B tagging algorithm:
  - ✓ Category-based (CB): physics object as Boosted decision tree (BDT) input
  - ✓ Similar to Belle & BaBar experiments
- Newly developed B tagging algorithm: GFlaT
  - ✓ Graph neural network (GNN)
  - ✓ 25 variables for each track as GNN input
  - ✓ 18% improvement in performance

$$\epsilon_{tag}(\text{CB}) = (31.7 \pm 0.5 \pm 0.4)\,\%$$
$$\epsilon_{tag}(\text{GFlaT}) = (37.4 \pm 0.4 \pm 0.3)\,\%$$

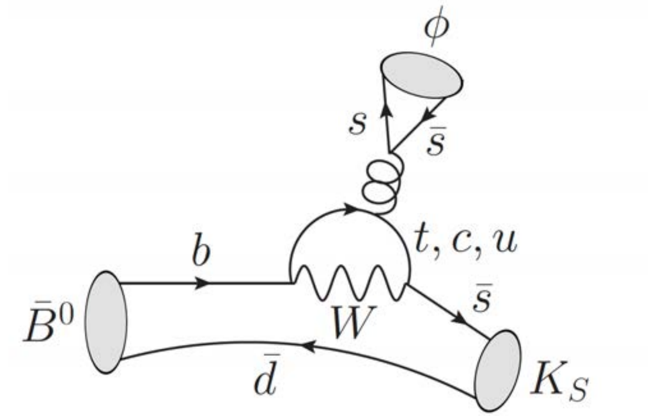
arXiv:2402.17260, Accepted by PRD



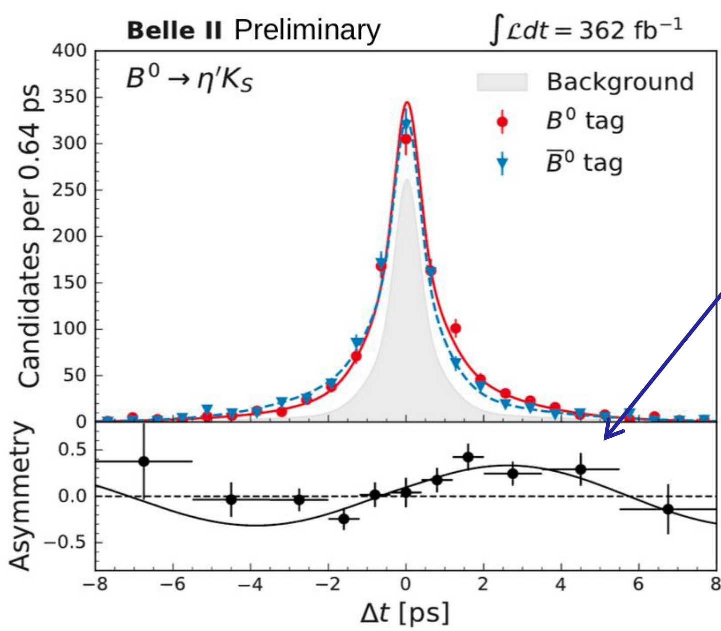


CPV in Penguin dominated B decays

NP may induce a large discrepancy between the CP Asymmetry in $b \to c\bar{c}s$ and $b \to q\bar{q}s, (q = u, d, s)$ transitions, such as $\eta' K_S^0,\ \phi K_S^0,\ K_S^0\pi^0,\ K_S^0 K_S^0 K_S^0$



$$B^0 \to \eta' K_S^0 \text{ with } \eta' \to \eta(\to \gamma\gamma, 3\pi)\pi^+\pi^- \text{ or } \eta' \to \rho\gamma$$



arXiv:2402.03713, PRD

$$\mathcal{A}_{CP}(\Delta t) = \frac{\Gamma(\bar{B}^0 \to \eta' K_s^0) - \Gamma(B^0 \to \eta' K_s^0)}{\Gamma(\bar{B}^0 \to \eta' K_s^0) + \Gamma(B^0 \to \eta' K_s^0)}$$
$$= S_{\eta' K_S^0} \sin(\Delta m_d \Delta t) - C_{\eta' K_S^0} \cos(\Delta m_d \Delta t)$$

- Still use the old Belle II CB tagging:

$$C_{\eta' K_S^0} = -0.19 \pm 0.08 \pm 0.03$$
$$S_{\eta' K_S^0} = +0.67 \pm 0.10 \pm 0.04$$

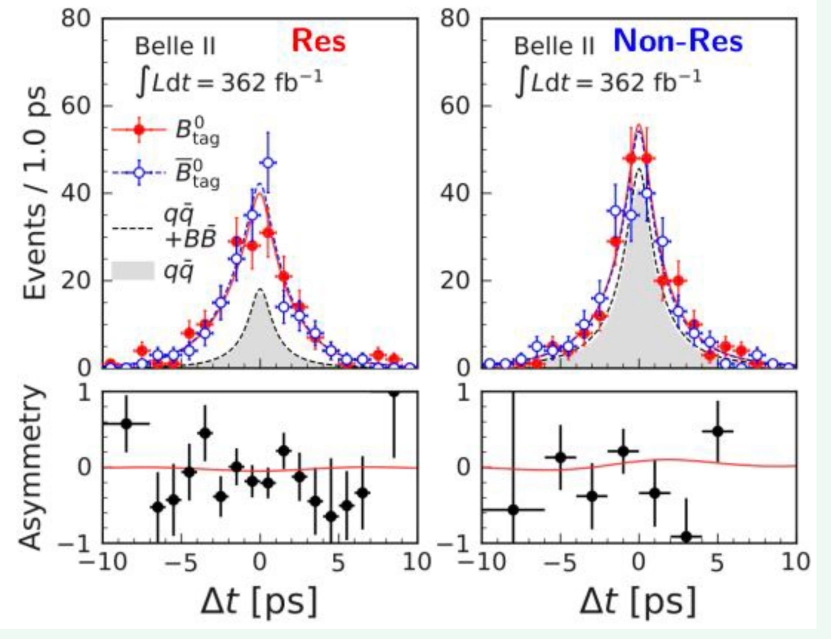
- Consistent with Belle measurement: 711 fb^{-1}
  - ✓ Use more final states ($K_S^0 \to \pi^0\pi^0,\ K_L$)
  - ✓ $\sigma_S = 0.07$
- Belle II expects ~10% improvement of σ_S for same data statistics using GFlaT

CPV in $B^0 \to K_S^0 \pi^0 \gamma$

- Amplitude dominated by electro-weak penguin loop
- Expect very small mixed-induced CPV in the Standard Model (SM)
  - ✓ $b \to s\gamma_R$ is helicity suppressed by (m_s/m_b) w.r.t. $b \to s\gamma_L$
  - ✓ $B^0 \to K_S^0\pi^0\gamma_L$ vs. $B^0 \to \bar{B}^0 \to K_S^0\pi^0\gamma_R$
- Measurements for resonance ($K^{*0} \to K_S^0\pi^0$) and non-resonance final states

$$
\begin{aligned}
C_{\text{Res}} &= 0.10 \pm 0.13 \pm 0.03 \\
S_{\text{Res}} &= 0.00\,^{+0.27}_{-0.26}\,^{+0.03}_{-0.04}
\end{aligned}
$$

$$
\begin{aligned}
C_{\text{Non-Res}} &= -0.06 \pm 0.25 \pm 0.07 \\
S_{\text{Non-Res}} &= 0.04\,^{+0.45}_{-0.44} \pm 0.10
\end{aligned}
$$



- Most precise measurements
  - ✓ Use CB tagging
  - ✓ Belle (499 fb^{-1}) & BaBar (436 fb^{-1})
- Challenging measurement at LHCb

To be submitted to PRL

Direct CPV in $B^0 \to \pi^0\pi^0$

- Update Belle II measurement of $\mathcal{B}$ and A_{CP} with 189 fb^{-1}
- Improved analysis techniques
  - ✓ Better selections, GFlaT, reduction of systematic uncertainties
  - ✓ BDT photon selector, continuum suppression trained using off-resonance data
  - ✓ 4-D fit: M_{bc}, ΔE, continuum suppression BDT output, wrong B-tag probability

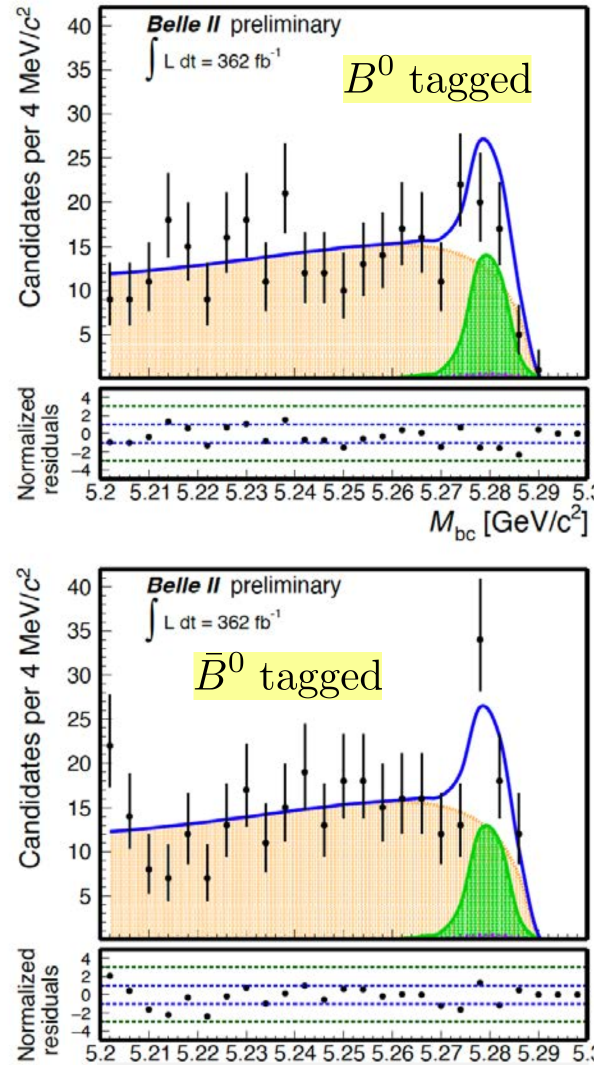
$$\mathcal{B} = (1.26 \pm 0.20 \pm 0.11) \times 10^{-6}$$
$$A_{\text{CP}} = 0.06 \pm 0.30 \pm 0.06$$

To be submitted to PRD

- Compatible Direct CP precision with world average
  - ✓ Belle ($499\ \text{fb}^{-1}$) & BaBar ($436\ \text{fb}^{-1}$)

$$\mathcal{B} = (1.59 \pm 0.26) \times 10^{-6}$$
$$A_{\text{CP}} = 0.30 \pm 0.20$$

  - ✓ Very challenging measurement at LHCb



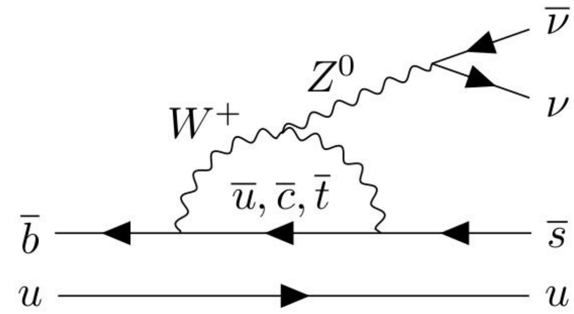
$$M_{bc} = \sqrt{(\sqrt{s}/2)^2 - |\vec{p}_B^{\,*}|^2}\ [\text{GeV/c}^2]$$

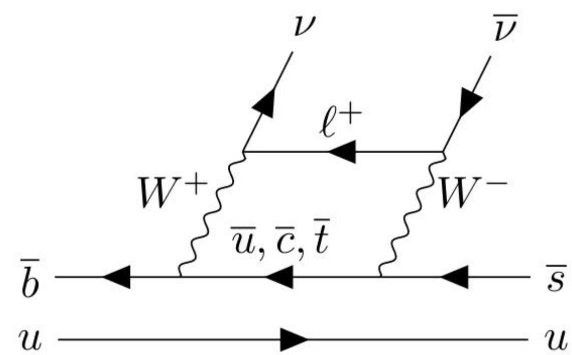
Electroweak Penguin dominated B decays

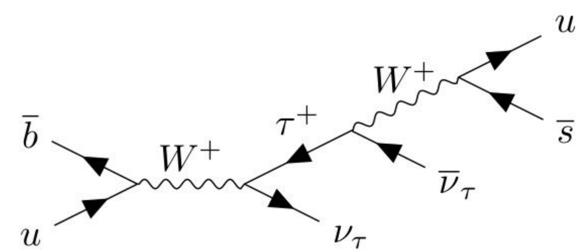
- NP may contribute, eg: the EWP loops
  - ✓ $b \to s l^+ l^-, b \to s\nu\bar{\nu}$, and $b \to s\gamma$ transitions
- Some measurements have tension with SM
  - ✓ Branching fraction and angular observables
- Search for $B^+ \to K^+ \nu\bar{\nu}$ at Belle II
  - ✓ Theoretically clean (no photon exchange)
  - ✓ Experimentally challenging: two neutrinos in the final state, high background and small branching fraction

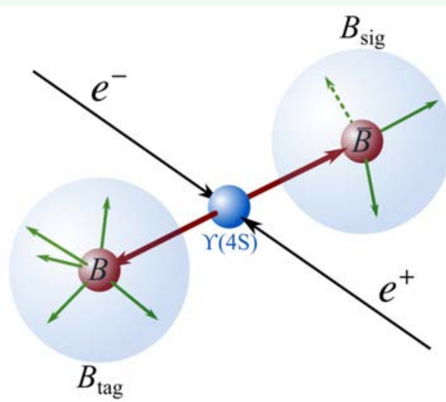
$$\mathcal{B}_{\rm SM} = (5.58 \pm 0.37) \times 10^{-6}$$

  - ✓ Only accessible at B-factories (constraint using well-know initial kinematics)



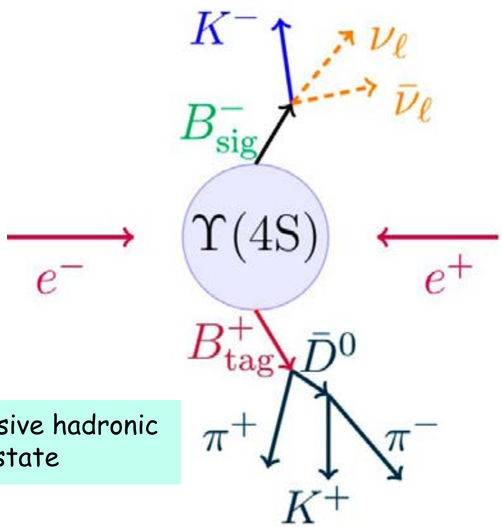






Search for $B^+ \to K^+ \nu\bar{\nu}$

Two parallel reconstructions



Exclusive hadronic final state

Hadronic Tag Analysis (HTA):

- Fully reconstruct "tag" B:
  - ✓ Better measurement of $B_{\rm sig}$ kinematic variables
- Full-Event-Interpretation (FEI) at Belle II
  - ✓ Multivariate classification using BDT
  - ✓ 50% tag efficiency improvement vs Belle
- Small efficiency but significantly reduce bg
  - ✓ Signal eff = 0.4%, purity = 3.5%
- Extract signal via a BDT output

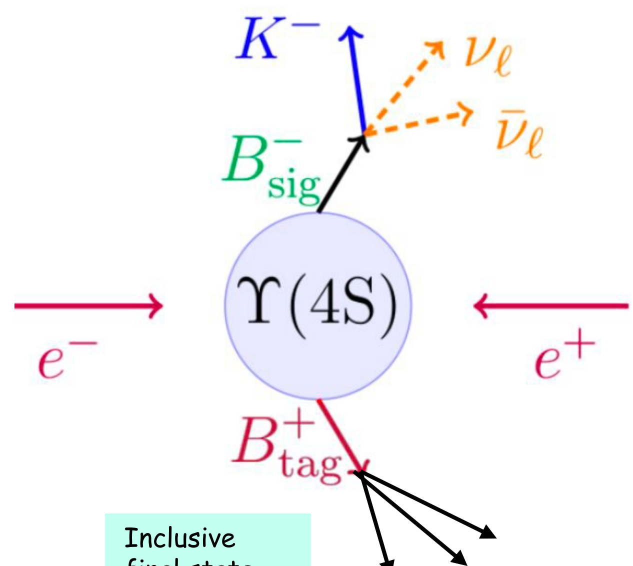
Comput. Softw. Big Sci. 3, 6 (2019)

Inclusive Tag Analysis (ITA):

- Non-exclusive reconstruction of "tag" B:
- Select signal kaon that minimize (~96% correct)

$$q^2_{\rm rec} = s/(4c^4) + m_K^2 - \sqrt{s}E_K^*/c^4$$

- Larger efficiency but significantly more bg
  - ✓ Signal eff = 8%, purity = 0.9%
- Extract signal using BDT output and q^2_{rec}

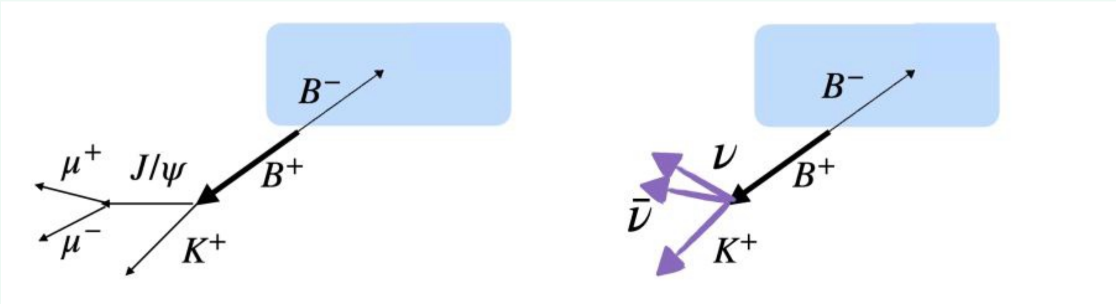


Inclusive final state

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

Data driven approach with many validations

- Signal efficiency check using $B \to J/\psi(\mu\mu)K$
  - ✓ Remove J/ψ and correct kaon kinematics to match signal distributions

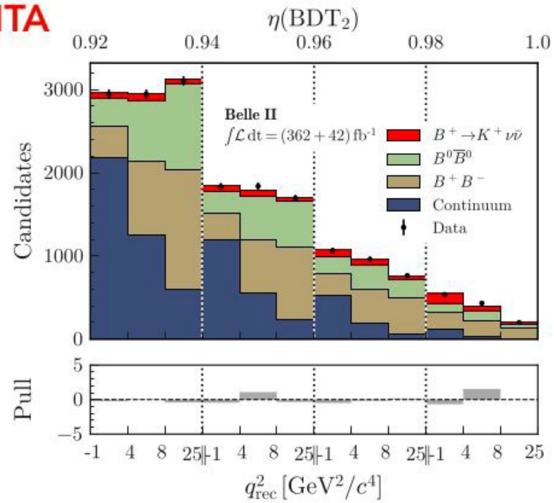


- Continuum validation with off-resonance data
- $B \to X_c(\to K_L^0)$ validate from pion enriched sideband
- Signal like $B \to K^+K_L^0K_L^0$ check with $B \to K^+K_S^0K_S^0$
- Similar validation for $B \to K^+K_S^0K_L^0$ and $B \to K^+nn$
- Validated the method to measure $B \to K^0\pi^+$
  - ✓ $\mathcal{B} = (2.5 \pm 0.5)\times10^{-5}$
  - ✓ Consistent with PDG: $(2.38 \pm 0.08)\times10^{-5}$

Phys. Rev. D 109, 112006 (2024)

Results of $B^+ \to K^+ \nu\bar{\nu}$

ITA



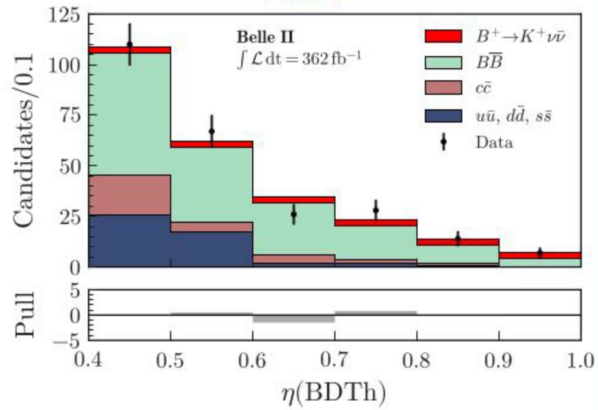
$\mu = 5.4 \pm 1.0(\mathrm{stat}) \pm 1.1(\mathrm{syst})$

corresponding to

$\mathcal{B}(B^+ \to K^+ \nu\bar{\nu}) = 2.7 \pm 0.5(\mathrm{stat}) \pm 0.5(\mathrm{syst}) \times 10^{-5}$

- 3.5 σ compatibility wrt bkg only
- 2.9 σ compatibility wrt to the SM

HTA



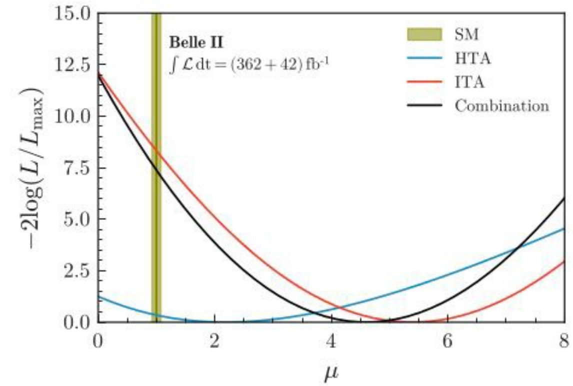
$\mu = 2.2^{+1.8}_{-1.7}(\mathrm{stat})^{+1.6}_{-1.1}(\mathrm{syst})$

corresponding to

$\mathcal{B}(B^+ \to K^+ \nu\bar{\nu}) = [1.1^{+0.9}_{-0.8}(\mathrm{stat})^{+0.8}_{-0.5}(\mathrm{syst})] \times 10^{-5}$

- 1.1 σ compatibility wrt bkg only
- 0.6 σ compatibility wrt to the SM

Combination



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

corresponding to

$\mathcal{B}(B^+ \to K^+ \nu\bar{\nu}) = [2.3 \pm 0.5(\mathrm{stat})^{+0.5}_{-0.4}(\mathrm{syst})] \times 10^{-5}$

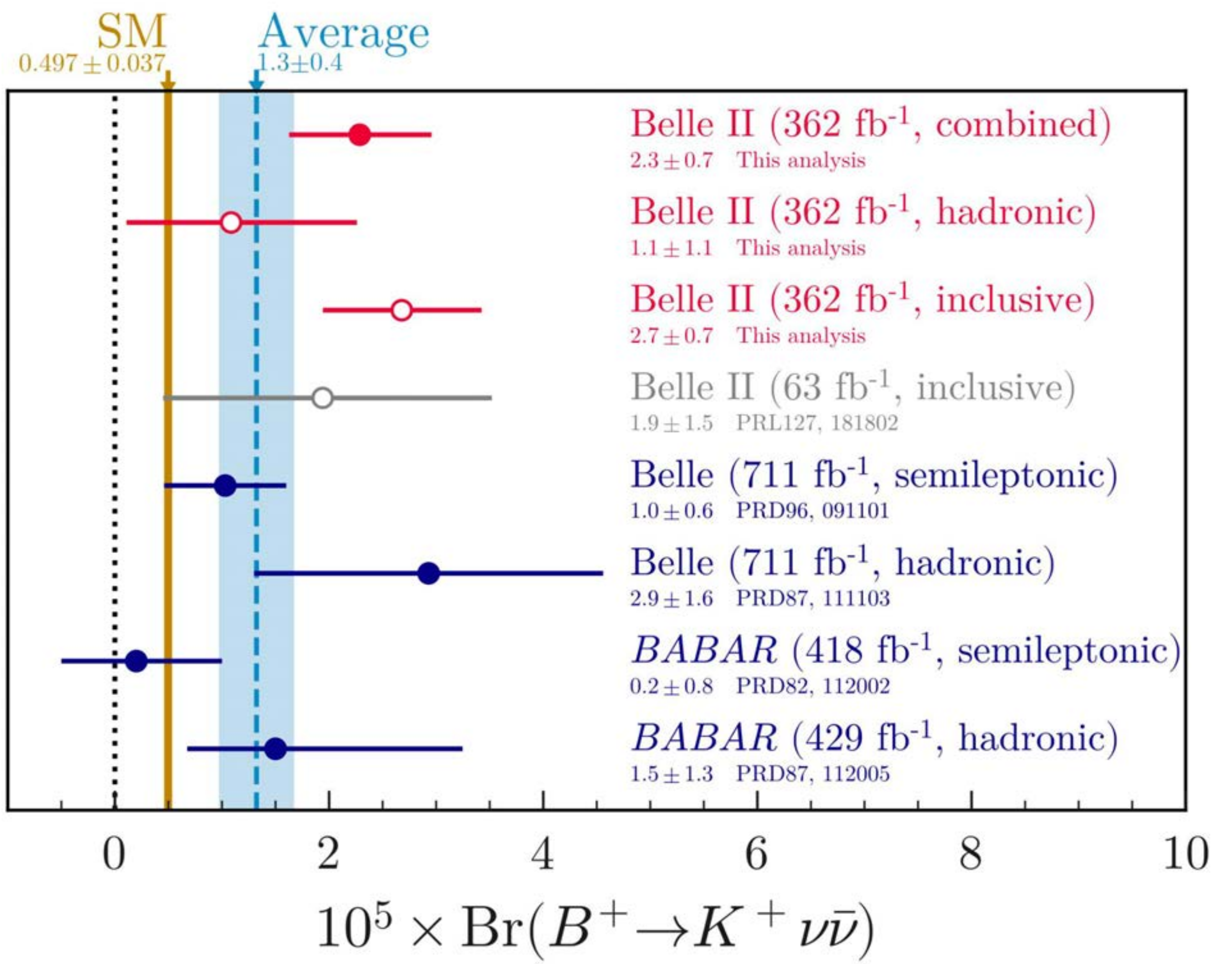
- Combination improves the ITA-only precision by 10%
- 3.5 σ significance wrt bkg
- 2.7 σ significance wrt SM

$$q^2_{\mathrm{rec}} = s/(4c^4) + m_K^2 - \sqrt{s}E_K^*/c^4$$

Phys. Rev. D 109, 112006 (2024)

- First evidence of $B^+ \to K^+ \nu\bar{\nu}$ (3.5σ), branching fraction in excess of SM 2.7σ
- Measurement enabled by new inclusive techniques

Results of $B^+ \to K^+ \nu\bar{\nu}$



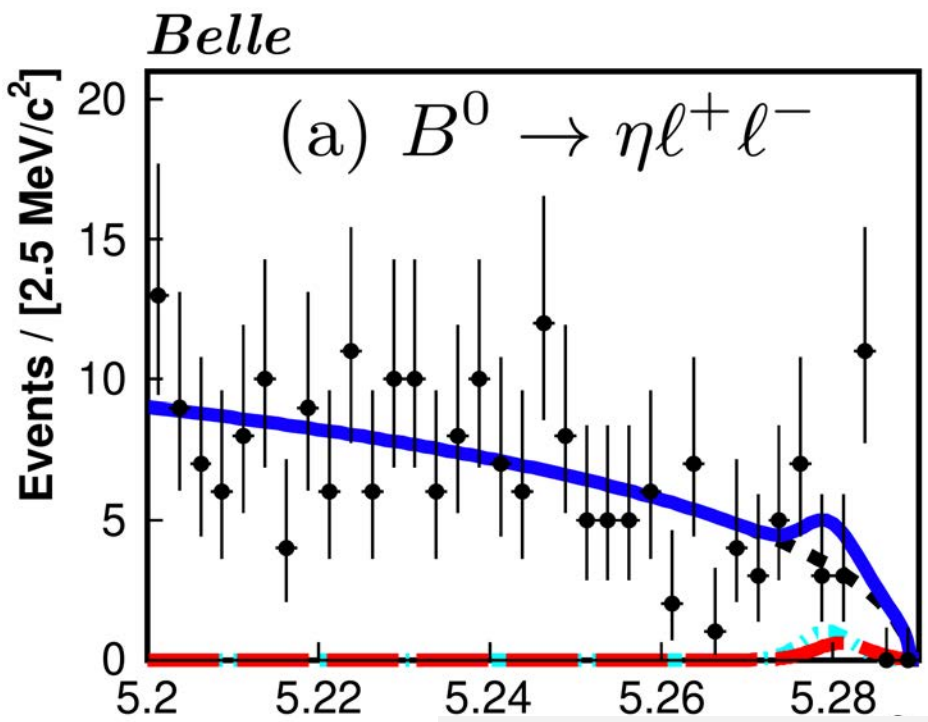
Other $B \to K\nu\bar{\nu}$ analysis ongoing at Belle II
Expect some results soon

Search for rare $b \to dl^+l^-$ transition

- $b \to dl^+l^-$ process via loops and highly suppressed, $\mathcal{B}_{SM} \sim O(10^{-8})$
  - ✓ LHCb (3 fb^{-1}) observed final state with $\pi^\pm$ in dimuon mode
- Sensitive to NP contribution in the loop
  - ✓ Rate measurement, lepton flavor universality

	$\mathscr{B}^{UL}(10^{-8})$	$\mathscr{B}(10^{-8})$
$B^0 \to \eta e^+e^-$	< 10.5	$0.0^{+4.9}_{-3.4} \pm 0.1$
$B^0 \to \eta \mu^+\mu^-$	< 9.4	$1.9^{+3.4}_{-2.5} \pm 0.2$
$B^0 \to \eta \ell^+\ell^-$	< 4.8	$1.3^{+2.8}_{-2.2} \pm 0.1$
$B^0 \to \omega e^+e^-$	< 30.7	$-2.1^{+26.5}_{-20.8} \pm 0.2$
$B^0 \to \omega \mu^+\mu^-$	< 24.9	$7.7^{+10.8}_{-7.5} \pm 0.6$
$B^0 \to \omega \ell^+\ell^-$	< 22.0	$6.4^{+10.7}_{-7.8} \pm 0.5$
$B^0 \to \pi^0 e^+e^-$	< 7.9	$-5.8^{+3.6}_{-2.8} \pm 0.5$
$B^0 \to \pi^0 \mu^+\mu^-$	< 5.9	$-0.4^{+3.5}_{-2.6} \pm 0.1$
$B^0 \to \pi^0 \ell^+\ell^-$	< 3.8	$-2.3^{+2.1}_{-1.5} \pm 0.2$
$B^+ \to \pi^+ e^+e^-$	< 5.4	$0.1^{+2.7}_{-1.8} \pm 0.1$
$B^0 \to \rho^0 e^+e^-$	< 45.5	$23.6^{+14.6}_{-11.2} \pm 1.1$
$B^+ \to \rho^+ e^+e^-$	< 46.7	$-38.2^{+24.5}_{-17.2} \pm 3.4$
$B^+ \to \rho^+ \mu^+\mu^-$	< 38.1	$13.0^{+17.5}_{-13.3} \pm 1.1$
$B^+ \to \rho^+ \ell^+\ell^-$	< 18.9	$2.5^{+14.6}_{-11.8} \pm 0.2$

arXiv:2404.08133, submitted to PRL

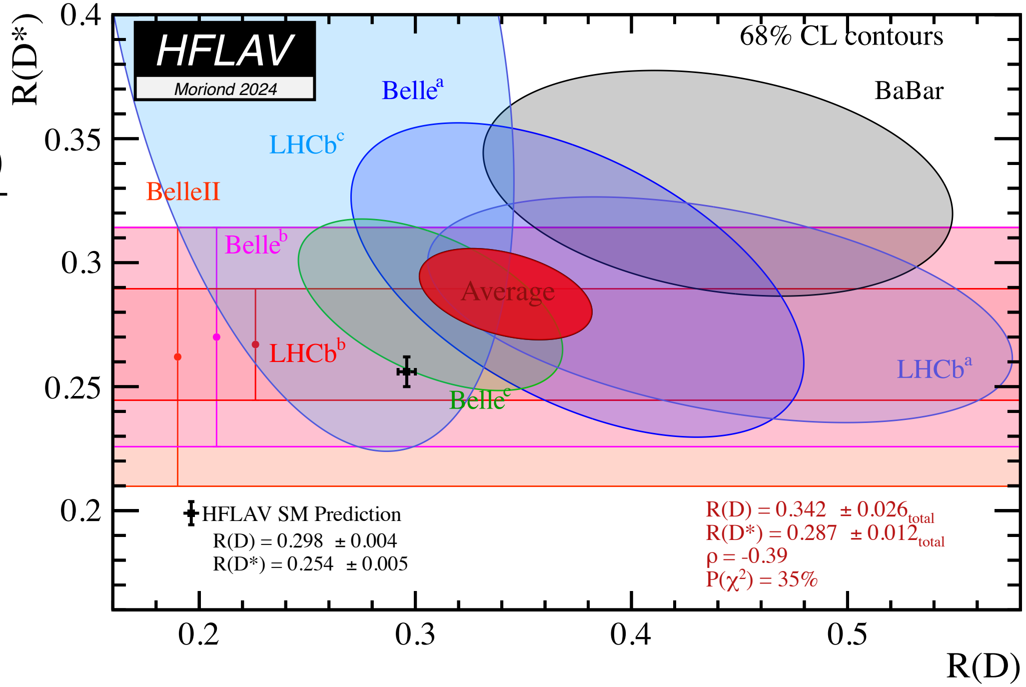


$M_{bc} = \sqrt{(\sqrt{s}/2)^2 - |\vec{p}^{\,*}_B|^2}$ [GeV/c^2]

Belle (711 fb^{-1})
World best limits in all channels. First search for ωl^+l^-, $\rho^0 e^+e^-$, $\rho^\pm l^+l^-$ modes

Test lepton Universality using $b \to c\tau\nu$

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



$$R_D = \frac{\mathcal{B}(B \to D\tau\nu)}{\mathcal{B}(B \to Dl\nu)}$$

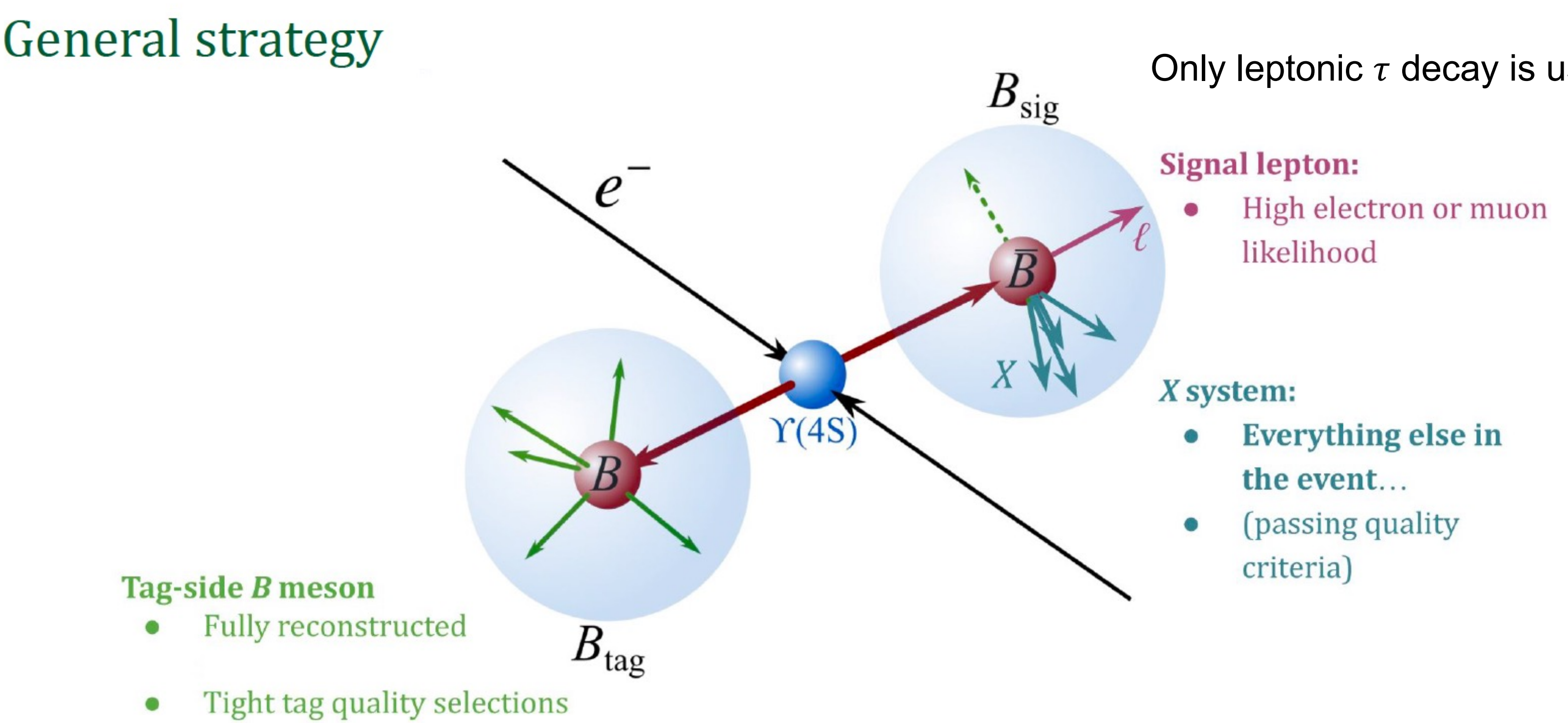
Measurement of R_D and R_{D^*} exceed the SM predictions by 1.6σ & 2.5σ, respectively, the combined deviation above the SM is 3.31σ

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

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

- Recent measurement by Belle II: $189\ \mathrm{fb}^{-1}$
  - Small statistical uncertainty due to large signal decay branching fraction
  - Phys. Rev. Lett. 132, 211804 (2024) Editor's suggestion

Test lepton Universality using $R(X_{\tau/l})$



Only leptonic τ decay is used

Using data-driven corrections for the “non-well-known” stuffs

Test lepton Universality using $R(X_{\tau/l})$

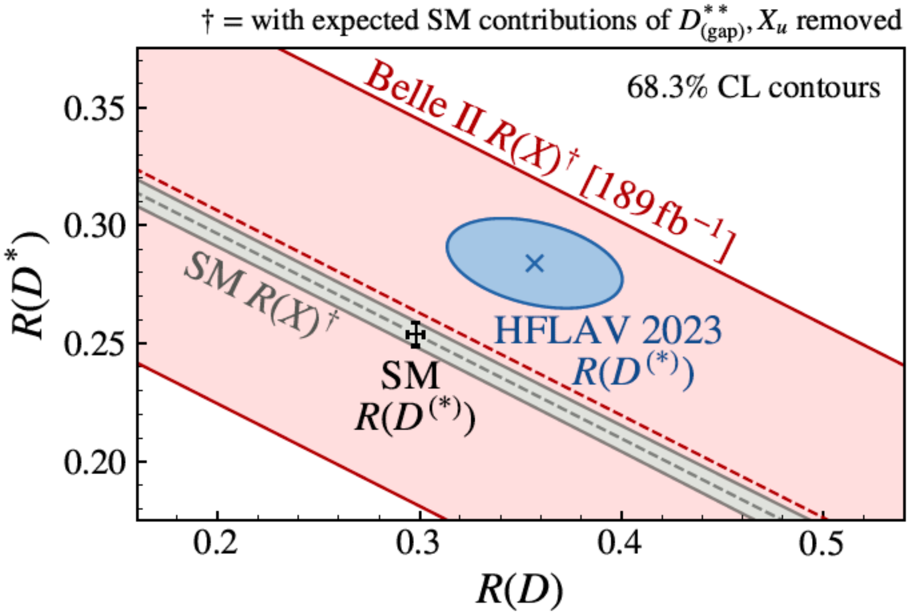
$$R(X_{\tau/\ell}) = 0.228 \pm 0.016(\text{stat}) \pm 0.036(\text{syst})$$

SM prediction: 0.223 ± 0.005

JHEP 2022,7(2022)
PRD 92,054018(2015)
PRD 105,073009 (2022)

Table I: Relative statistical and systematic uncertainties on the value of $R(X_{\tau/\ell})$ for electrons, muons, and their combination (ℓ). Detailed descriptions of each source are provided in the text.

Source	Uncertainty [%]		
	e	μ	ℓ
Experimental sample size	8.8	12.0	7.1
Simulation sample size	6.7	10.6	5.7
Tracking efficiency	2.9	3.3	3.0
Lepton identification	2.8	5.2	2.4
$X_c\ell\nu$ reweighting	7.3	6.8	7.1
$B\overline{B}$ background reweighting	5.8	11.5	5.7
$X\ell\nu$ branching fractions	7.0	10.0	7.7
$X\tau\nu$ branching fractions	1.0	1.0	1.0
$X_c\tau(\ell)\nu$ form factors	7.4	8.9	7.8
Total	18.1	25.6	17.3



Phys. Rev. Lett. 132, 211804 (2024)
Editor's suggestion

- Belle II has developed a powerful and independent new test of the $b \to c\tau\nu$ anomaly using new inclusive techniques
- Measurement limited by systematic errors, some of them can be reduced with more data/MC events

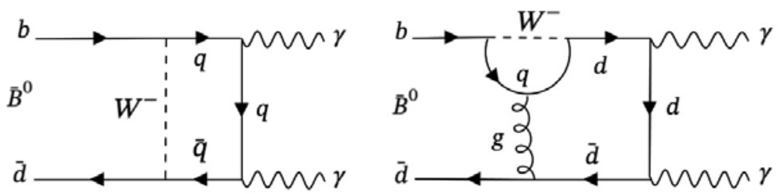
Measurement of $B \to \gamma\gamma$

- Combined Belle ($694\ \mathrm{fb}^{-1}$) and Belle II ($362\ \mathrm{fb}^{-1}$) measurement

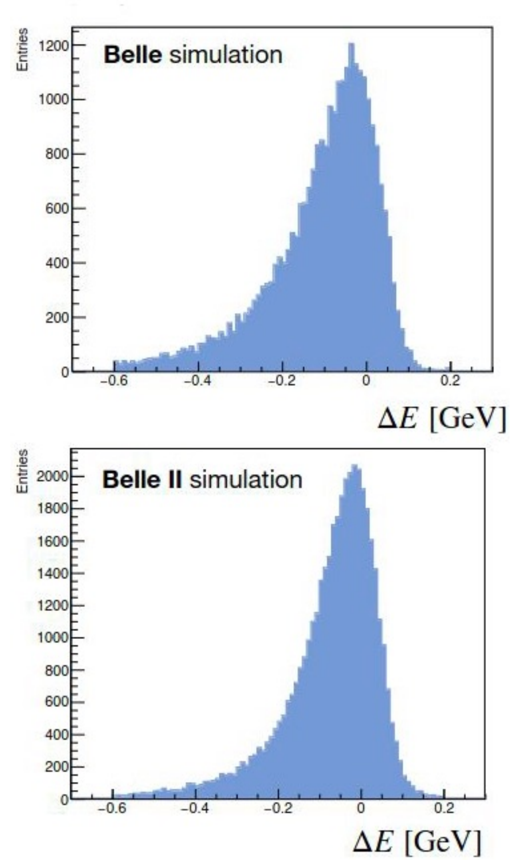
- Small branching fraction & high background

- Analysis strategy:
  - ✓ Dedicated BDT to suppress continuum, $\pi^0 \to \gamma\gamma$ and $\eta^0 \to \gamma\gamma$
  - ✓ Multivariable fit to: $\Delta E, M_{bc}$, and BDT output
  - ✓ Control sample: $B^0 \to K^*(892)[K^+\pi^-]\gamma$

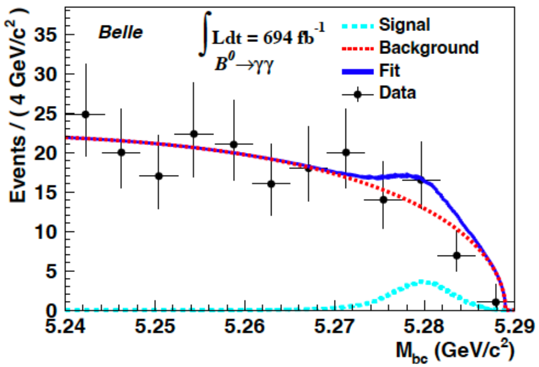
- Significant improvement at Belle II vs Belle
  - ✓ Better signal efficiency
  - ✓ Improved ΔE resolution

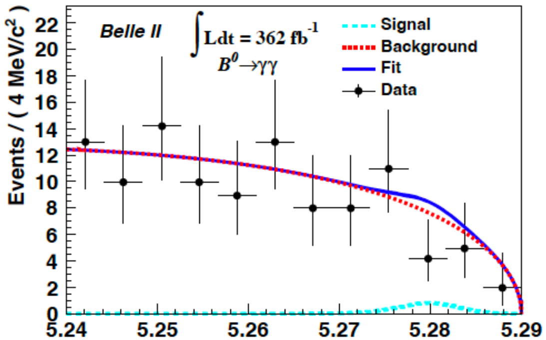


	Belle	Belle II
Sig efficiency	23%	31%
Exp. bkg/fb^{-1}	~ 0.8	



Measurements of $B \to \gamma\gamma$





arXiv:2405.19734, submitted to PRD

$M_{bc} = \sqrt{(\sqrt{s}/2)^2 - |\vec{p}_B^{\,*}|^2}$ [GeV/c^2]

- Combined signal yield: $11.0^{+6.5}_{-5.5}$
  - ✓ Significance ~ 2.5σ and Expected UL: $\mathcal{B} < 4.4\times10^{-8}$

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

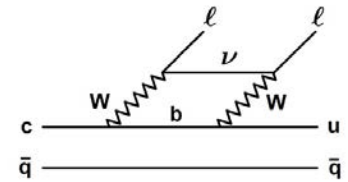
	$\mathcal{B}(B^0 \to \gamma\gamma)$	UL on $\mathcal{B}(B^0 \to \gamma\gamma)$
Belle	$(5.4^{+3.3}_{-2.6} \pm 0.5) \times 10^{-8}$	$< 9.9 \times 10^{-8}$
Belle II	$(1.7^{+3.7}_{-2.4} \pm 0.3) \times 10^{-8}$	$< 7.4 \times 10^{-8}$
Combined	$(3.7^{+2.2}_{-1.8} \pm 0.5) \times 10^{-8}$	$< 6.4 \times 10^{-8}$

- Sensitivity approaches SM prediction: $\mathcal{B} = (1.4^{+1.4}_{-0.8})\times10^{-8}$
- UL has 5x improvement over previous best UL by BaBar: $\mathcal{B} < 3.2\times10^{-7}$
- Possible observation with more data in near future

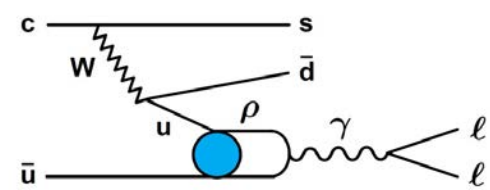
Search for Rare Charm decays: $D^0 \to h^+h^-e^+e^-$

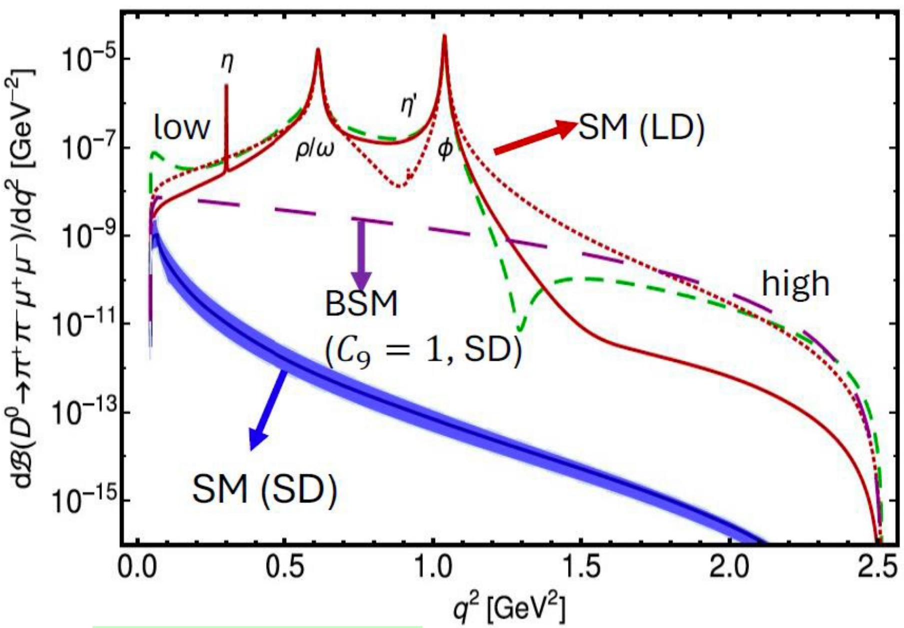
- Flavor changing neutral current (FCNC) $c \to ull$ process is highy suppressed in the SM
- LD mainly from vector meson dominated mode
- Search for NP and Lepton Flavor Universality (LFU) test

Short distance (SD)



Long distance (LD)





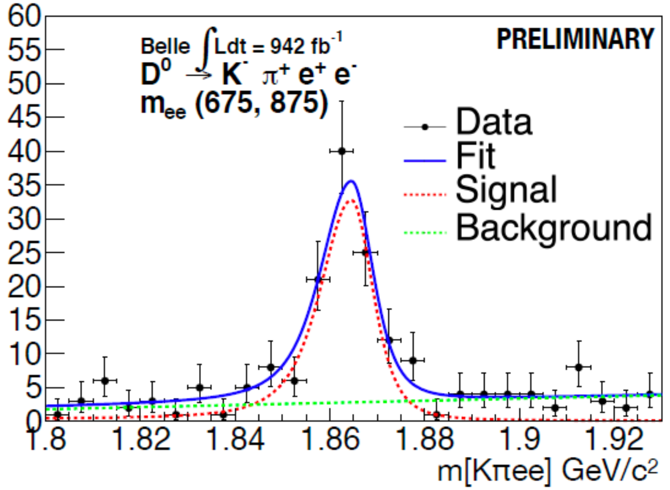
PRD 98, 035041 (2018)

Some previous results of Br and UL (10^{-7}) @90%

Experiment	$K^-K^+e^+e^-$	$\pi^-\pi^+e^+e^-$	$K^-\pi^+e^+e^-$
Babar (2019)			$40.0 \pm 5.0 \pm 2.3$ (ρ^0/ω) stat syst
BESIII (2019)	< 110	< 70	< 410
	$K^-K^+\mu^+\mu^-$	$\pi^-\pi^+\mu^+\mu^-$	$K^-\pi^+\mu^+\mu^-$
LHCb (2016-2017)	$1.54 \pm 0.27 \pm 0.19$	$9.64 \pm 0.48 \pm 1.10$	$4.17 \pm 0.12 \pm 0.40$ (ρ^0/ω)

BaBar: PRL 122, 081802 (2019)
BESIII: PRD 97, 072015 (2019)
LHCb: PLB 517, 558 (2016); PRL 119, 181805 (2017)

Search for rare charm decays: $D^0 \to h^+h^-e^+e^-$



To be submitted to PRL

- Belle measurement with 942 fb^{-1} data
- Observe $D^0 \to K^-\pi^+e^+e^-$ in ρ/ω region (11.8σ)
  - ✓ Compatible with Babar and SM expectation

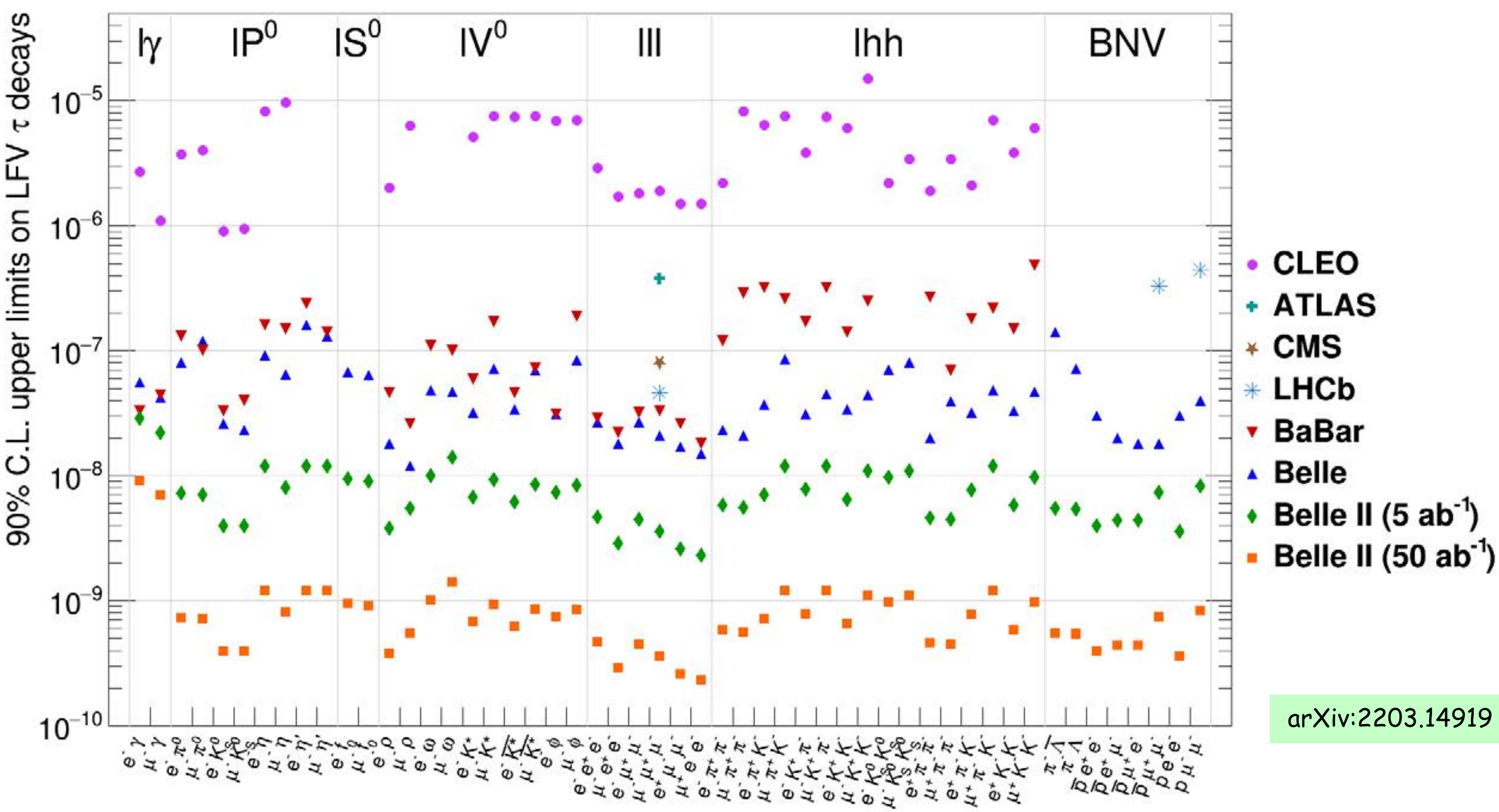
$$\mathcal{B} = (39.6 \pm 4.5(\text{stat}) \pm 2.9(\text{syst})) \times 10^{-7}$$

- No significant signal on other final states
  - ✓ UL at 90% around $(2.3 - 7.7)\times 10^{-7}$
  - ✓ World's best limits to date

m_{ee} region	[MeV/c^2]	Yield	Significance	$\mathcal{B}$ [10^{-7}]	UL @ 90% CL [10^{-7}]	Efficiency
$K^-K^+e^+e^-$						
η	520-560	-	$< 0.1\sigma$	-	< 2.3	3.53 ± 0.04
ρ^0/ω	> 675	2.6 ± 1.8	2.0σ	$1.2 \pm 0.9 \pm 0.1$	< 3.0	6.00 ± 0.06
non-resonant	> 200 [a]	3.5 ± 3.3	1.5σ	$3.1 \pm 3.0 \pm 0.4$	< 7.7	3.19 ± 0.04
$\pi^-\pi^+e^+e^-$						
η	520-560	0.6 ± 2.3	0.3σ	$0.4 \pm 1.4 \pm 0.2$	< 3.2	5.31 ± 0.05
ρ^0/ω	675-875	3.7 ± 4.1	0.9σ	$2.0 \pm 2.2 \pm 0.8$	< 6.1	5.69 ± 0.05
ϕ	995-1035	3.6 ± 3.2	1.1σ	$1.1 \pm 1.1 \pm 0.2$	< 3.1	9.41 ± 0.06
non-resonant	> 200	-0.2 ± 4.1	$< 0.1\sigma$	$-0.2 \pm 3.4 \pm 0.9$	< 7.2	3.69 ± 0.04
$K^-\pi^+e^+e^-$						
η	520-560	4.0 ± 2.7	1.6σ	$2.2 \pm 1.5 \pm 0.5$	< 5.6	5.09 ± 0.04
ρ^0/ω	675-875	110 ± 13	11.8σ	$39.6 \pm 4.5 \pm 2.9$	-	8.01 ± 0.06
ϕ	990-1034	4.6 ± 2.4	2.5σ	$1.4 \pm 0.8 \pm 0.3$	< 2.9	9.19 ± 0.06
non-resonant	> 560	2.2 ± 4.2	0.4σ	$1.3 \pm 2.4 \pm 0.6$	< 6.5	4.89 ± 0.09

Search for Rare τ lepton decays

- Many rare or forbidden τ decays are excellent probes to NP beyond the SM
- B-factories generated large τ decay data samples
  - ✓ Searches in many different final states with high precisions
  - ✓ Not limited by systematics, sensitivities increases with higher luminosity
  - ✓ Better sensitives than other experiments in many final states

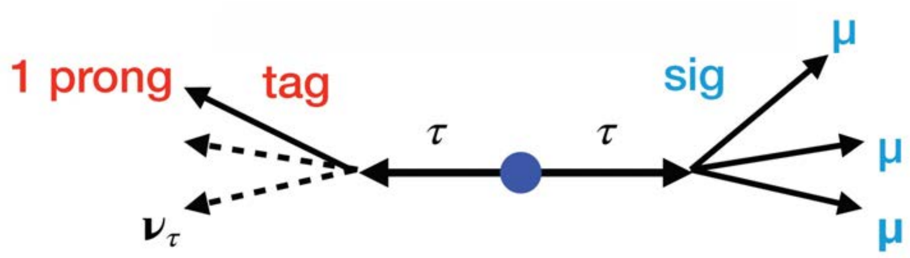


arXiv:2203.14919

Search for LFV $\tau \to \mu\mu\mu$ decay

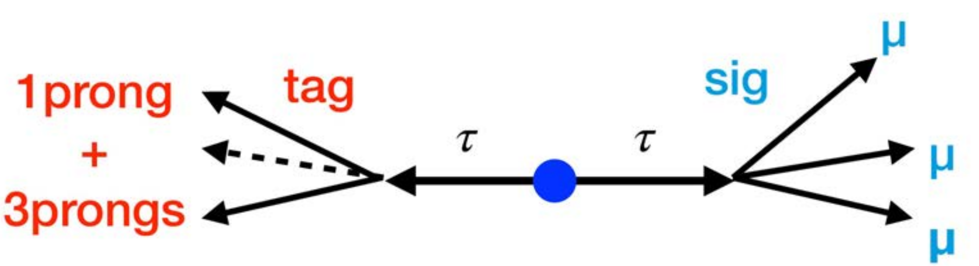
Belle II measurements: $424\ \text{fb}^{-1}$ data

1-prong: Belle & BaBar method



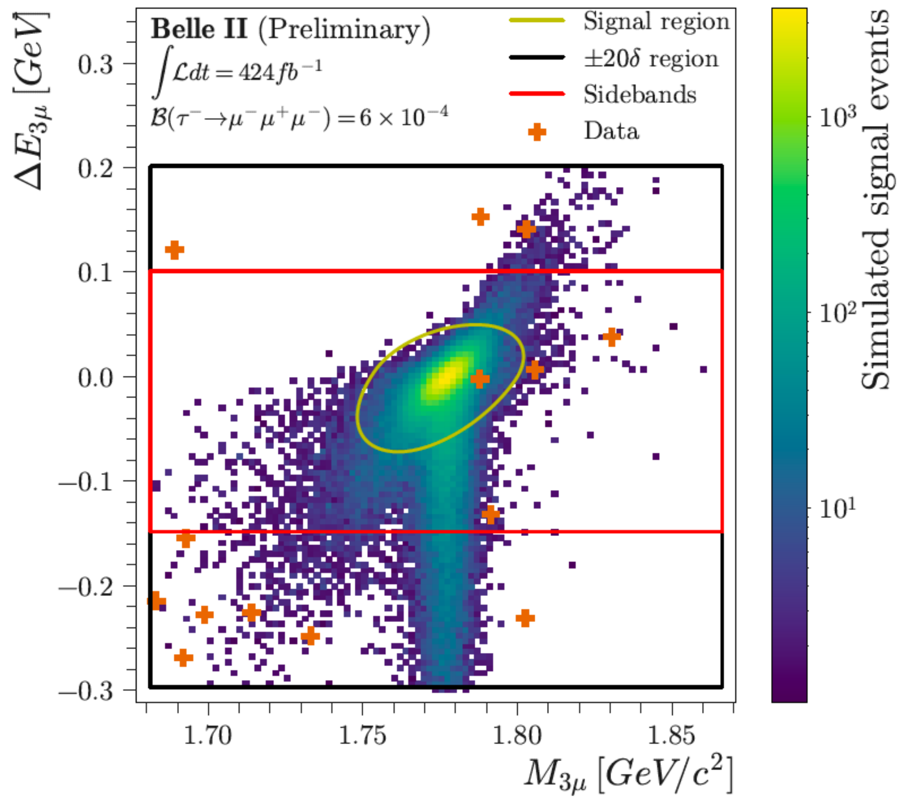
- Cut-based selection
- Signal efficiency: 14.9% (2 × Belle efficiency)
- Expected background: 0.43 (simulation)

Inclusive approach: Belle II



- Boost Decision Tree based selection
- Signal efficiency: 20.4% (2.7 × Belle efficiency)
- Expected background: 0.5 (simulation)

Search for LFV $\tau \rightarrow \mu\mu\mu$ decay



$$M_{3\mu} = \sqrt{E_{3\mu}^2 - |\vec{p}_{3\mu}|^2}$$

$$\Delta E = E_{3\mu}^{\text{CM}} - E_{\text{beam}}^{\text{CM}}$$

Signal:
$M_{3\mu}$ close to τ mass,
ΔE close to zero
Tail due to initial and final radiations

Experiment	Upper Limit at 90% C.L.
ATLAS	3.8×10^{-7} ($\mathscr{L} = 20.3$ fb^{-1})
LHCb	4.6×10^{-8} ($\mathscr{L} = 3.0$ fb^{-1})
CMS	2.9×10^{-8} ($\mathscr{L} = 131$ fb^{-1})

CMS - PLB 853 (2024) 138633

Experiment	Upper Limit at 90% C.L.
Belle	2.1×10^{-8} ($\mathscr{L} = 782$ fb^{-1})
BaBar	3.3×10^{-8} ($\mathscr{L} = 486$ fb^{-1})
Belle II	1.9×10^{-8} ($\mathscr{L} = 424$ fb^{-1})

Belle II - arXiv:2405.07386

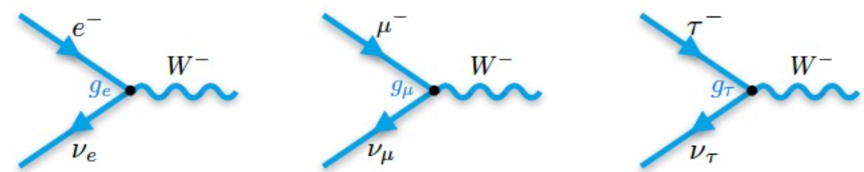
Most stringent limit to date

Test of Lepton flavour universality in τ decay

Belle II

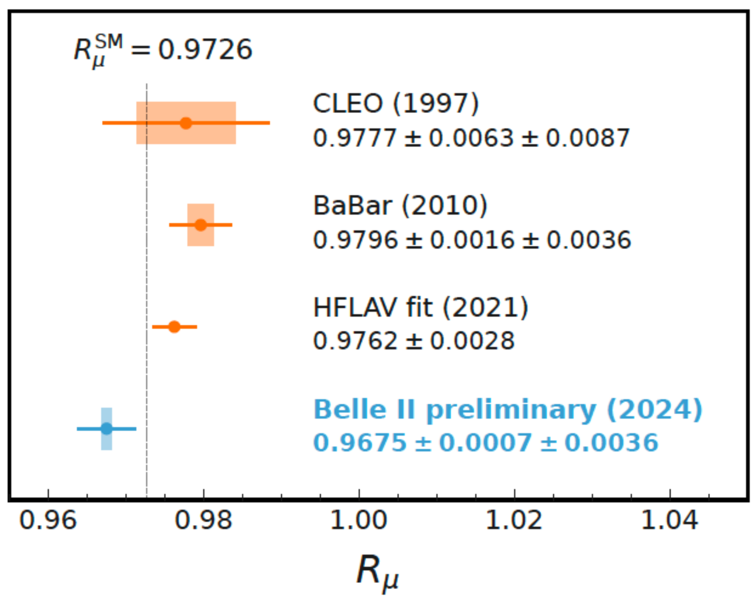
- Coupling between lepton and W is flavour-independent in the SM
- Test $\mu - e$ universality in τ decays by measuring decay rates ($362\ \mathrm{fb}^{-1}$)

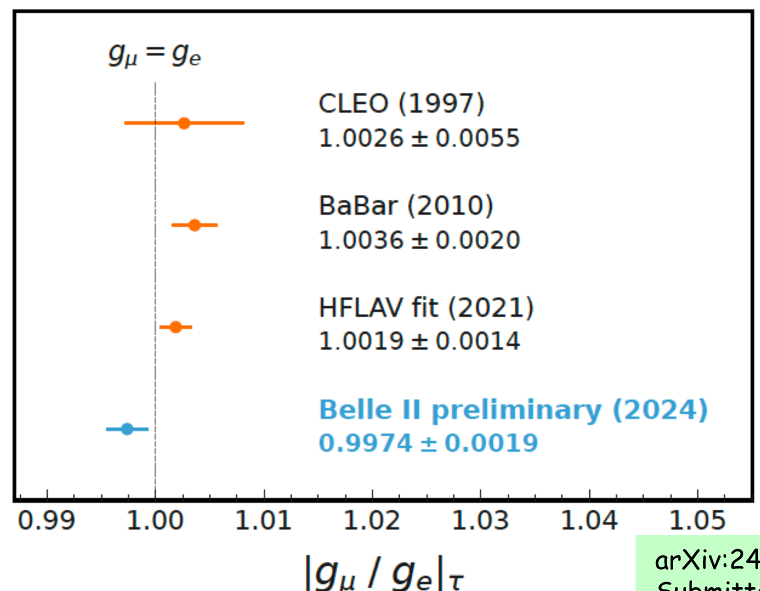
$$g_e = g_\mu = g_\tau$$



$$R_\mu = \frac{B(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau)}{B(\tau^- \to e^- \bar{\nu}_e \nu_\tau)} \overset{\mathrm{SM}}{=} 0.9726$$

$$\left(\frac{g_\mu}{g_e}\right)^2_\tau \propto R_\mu \times \frac{f(m_e^2/m_\tau^2)}{f(m_\mu^2/m_\tau^2)} \overset{\mathrm{SM}}{=} 1$$



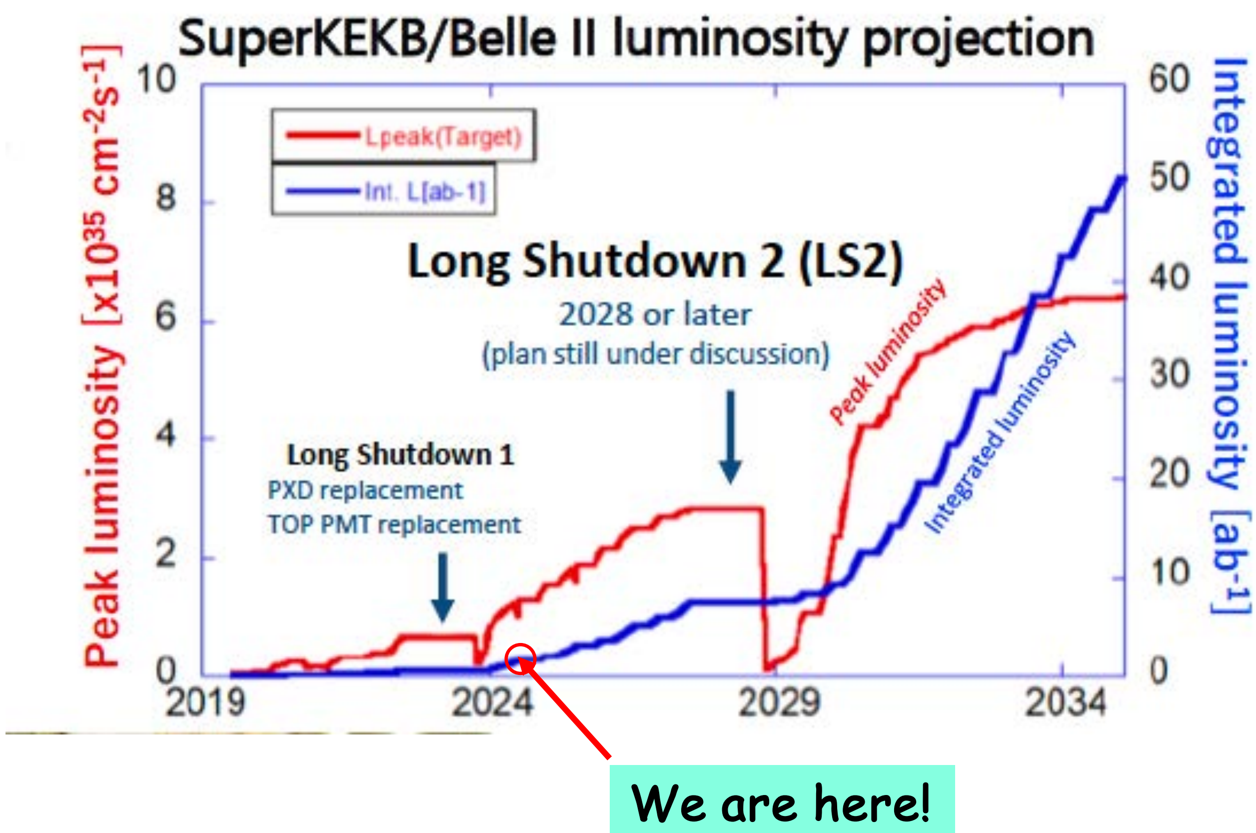


arXiv:2405.14625
Submitted to JHEP

- Most precise test of $\mu - e$ universality in τ decays by a single measurement
- Consistent with the SM expectation at 1.4σ level
- Dominated systematic uncertainty by Lepton ID corrections and correlations

Summary and Prospect

- A few selected recent highlights from Belle(II)
- Improved sensitivities at Belle II (better detector and analysis)
- **More exciting results will eventually come with more data (soon)**



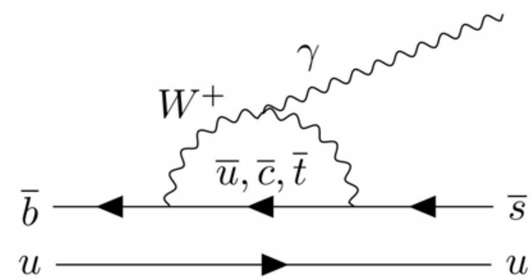
Backup

Measurements of $B \to K^*(892)\gamma$

Large branching fraction and clean experimental signal

$$\mathcal{B} = \frac{N_{\overline{B}}/\epsilon_{\overline{B}} + N_B/\epsilon_B}{2 \times N_{B\overline{B}} \times f^{+-}(f^{00})}, \quad \Delta_{0+} = \frac{(\tau_+/\tau_0) \times \mathcal{B}(B^0 \to K^{*0}\gamma) - \mathcal{B}(B^+ \to K^{*+}\gamma)}{(\tau_+/\tau_0) \times \mathcal{B}(B^0 \to K^{*0}\gamma) + \mathcal{B}(B^+ \to K^{*+}\gamma)},$$

$$\mathcal{A}_{CP} = \frac{N_{\overline{B}}/\epsilon_{\overline{B}} - N_B/\epsilon_B}{N_{\overline{B}}/\epsilon_{\overline{B}} + N_B/\epsilon_B}, \quad \Delta\mathcal{A}_{CP} = \mathcal{A}_{CP}(B^+ \to K^{*+}\gamma) - \mathcal{A}_{CP}(B^0 \to K^{*0}\gamma),$$



Belle II Results: 362 fb^{-1}

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

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

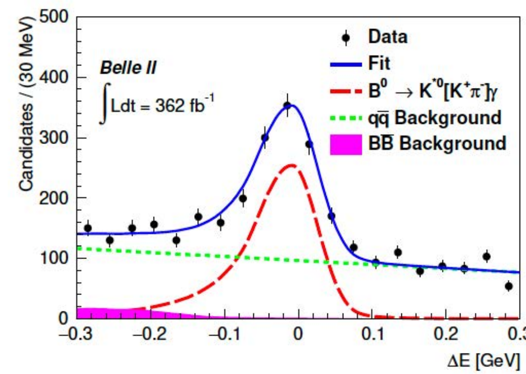
$$\mathcal{A}_{CP}[B^0 \to K^{*0}\gamma] = (-3.2 \pm 2.4 \pm 0.4)\%,$$

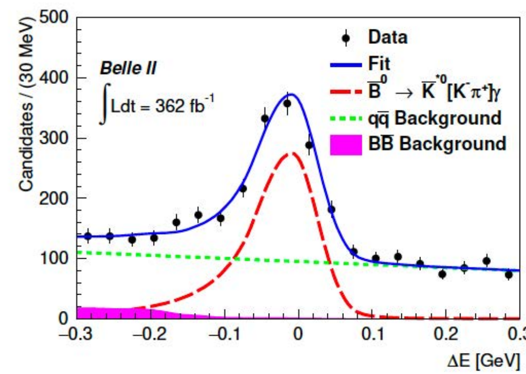
$$\mathcal{A}_{CP}[B^+ \to K^{*+}\gamma] = (-1.0 \pm 3.0 \pm 0.6)\%,$$

$$\Delta A_{\mathrm{CP}} = (2.2 \pm 3.8 \pm 0.7)\%$$

$$\Delta_{0+} = (5.1 \pm 2.0 \pm 1.0 \pm 1.1)\%$$

Stat Syst f^{+-}/f^{00}





To be submitted to JHEP

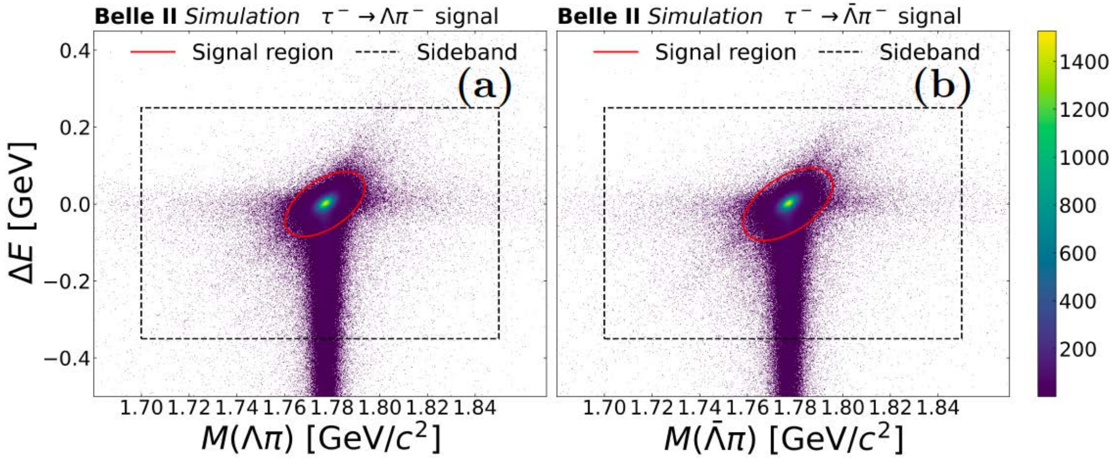
Consistent with the world average and the SM expectation
Systematic uncertainties can be reduced with more data

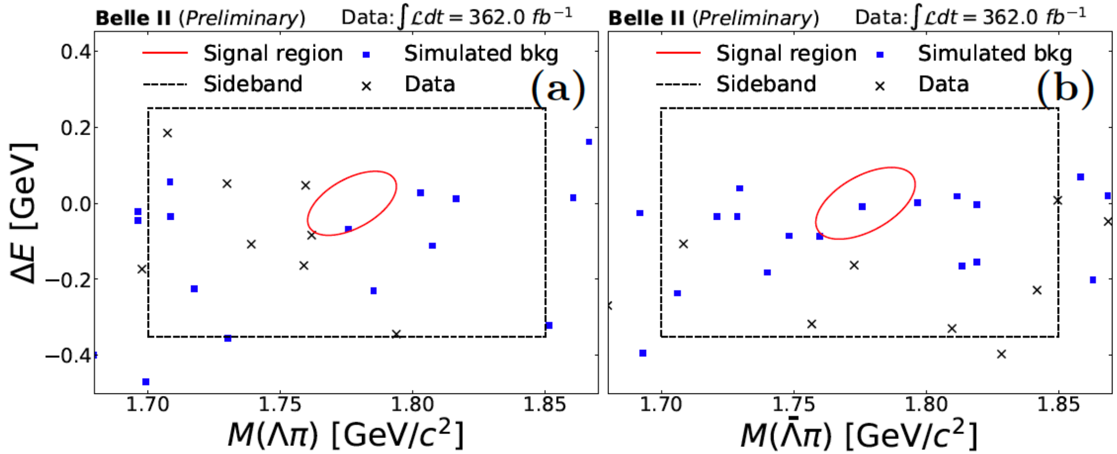
Lepton & baryon number violating τ decay

- Search for Lepton number & baryon number violating τ decays

$$\tau^- \to \Lambda\pi^- \quad \text{and} \quad \tau^- \to \bar{\Lambda}\pi^-$$

- Belle II measurements: $362\ \text{fb}^{-1}$ data





$$\mathcal{B}(\tau^- \to \Lambda\pi^-) < 4.7 \times 10^{-8} \quad @90\,\%\text{CL}$$
$$\mathcal{B}(\tau^- \to \bar{\Lambda}\pi^-) < 4.3 \times 10^{-8} \quad @90\,\%\text{CL}$$

To be submitted to PRD