[FJPPN-FLAV_06]
Precise Measurements and Searches for Forbidden Decays of B mesons and tau leptons

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Justine Serrano (CPPM)

FLAV_06

- Title : Precise measurements and searches for forbidden decays of B mesons and tau leptons

- PIs : Justine Serrano (CPPM)  , Akimasa Ishikawa (KEK) 
  - Both are experimentalists working on Belle II while joint effort with theorists is the key for this project. Exp + Pheno + Lattice QCD
  - Great helps from previous PIs, E. Kou (IJClab, Pheno) and T. Kaneko (KEK, Lattice QCD)

- Topics : Flavor Physics at SuperKEKB/Belle II
  - Focusing on precise measurements of lepton flavor universality (LFU) and search for forbidden decays via lepton flavor violation (LFV)
  - Other important analyses such as precise measurements of CPV and angular distributions in $b \rightarrow s\gamma$ included.

The Team

- 5 members from French side
- 6 members from Japanese side

Strong team!

Group Members

France

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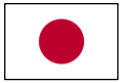

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Introduction

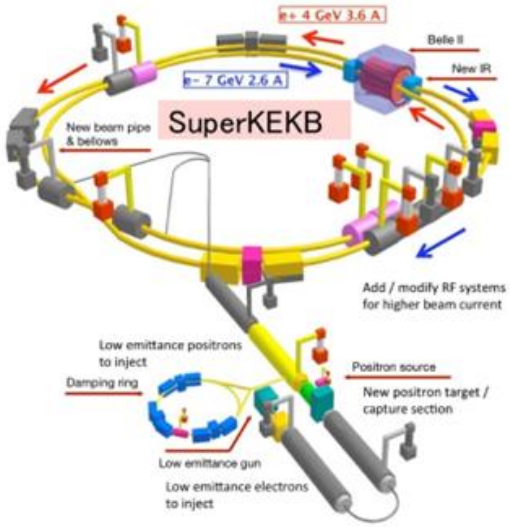
SuperKEKB/Belle II

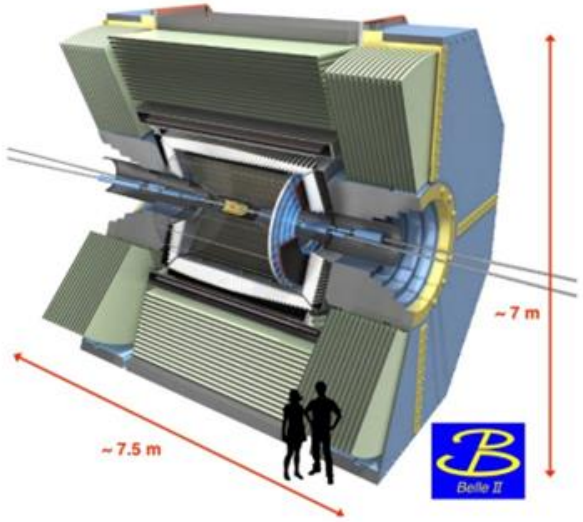
- SuperKEKB
  - World highest luminosity collider located at KEK, Tsukuba, Japan

    Peak luminosity

    5.244 x 10^{34} ($cm^{-2}s^{-1}$), March 19, 2026.

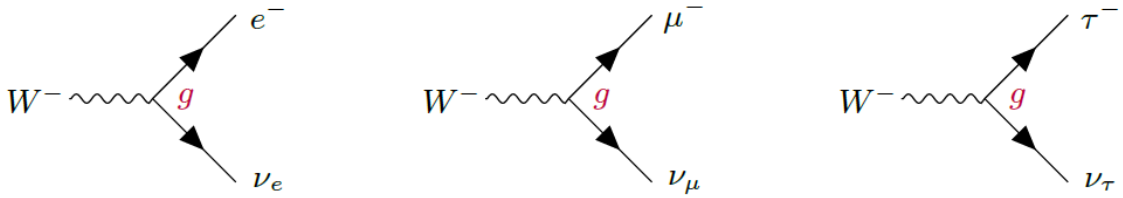
- Belle II
  - World highest data set 50ab^{-1} to be collected
    - Including 5x10^{10} B meson pairs and τ lepton pairs
  - Plan to accumulate more than 1ab^{-1} data in this year
    - Larger data than KEKB/Belle
    - Now we can collect the same amount data as BaBar in one year.



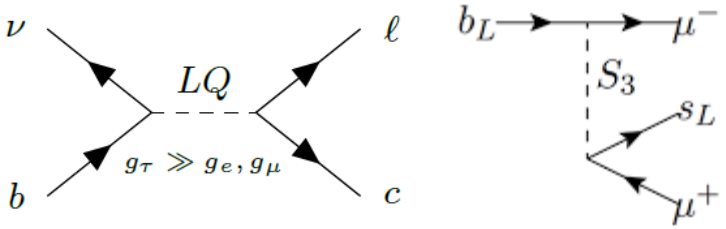


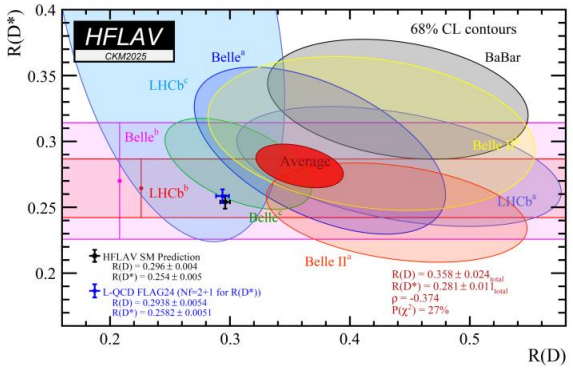
LFU

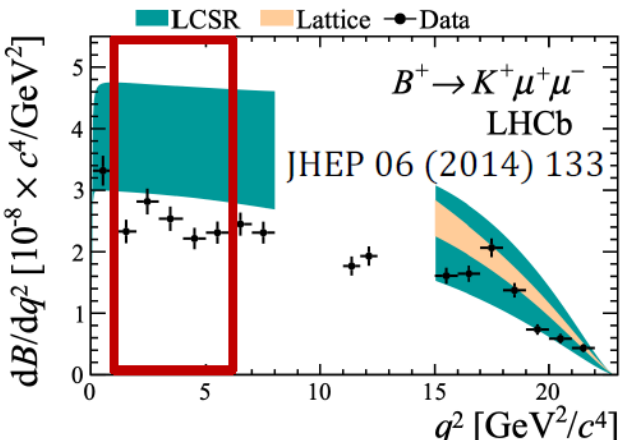
- Lepton Flavor Universality
  - Couplings of leptons are exactly the same in the SM



  - 3.8σ deviation for b→cτν
  - More than 5σ deviation in b→sμμ
    - naïve average
  - New physics contributions?

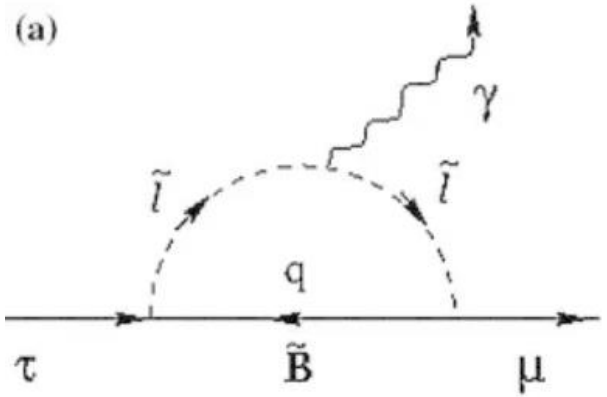


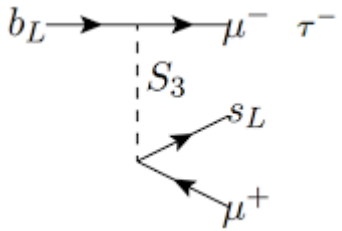




LFV

- Lepton Flavor Violation
  - Forbidden in the SM
    - Even considering ν oscillation BF < 10^{-54}
  - Allowed in many new physics models
    - SUSY
    - Seesaw
    - Leptoquark
    - …
- LFV might be associated with LFU violation
  - Leptoquark





Activities in JFY2025

Forbidden Decays : τ LFV decays

τ → ell' (l=e,μ) with Belle II data (424fb^{-1})

- Uses an analysis method developed for τ → 3μ to search for other final states with 3 leptons
- Signal obtained from fit of the reconstructed τ mass for the 5 modes
- Published in JHEP: JHEP12(2025)169

τ → lKs with Belle + Belle II data (1.4ab^{-1})

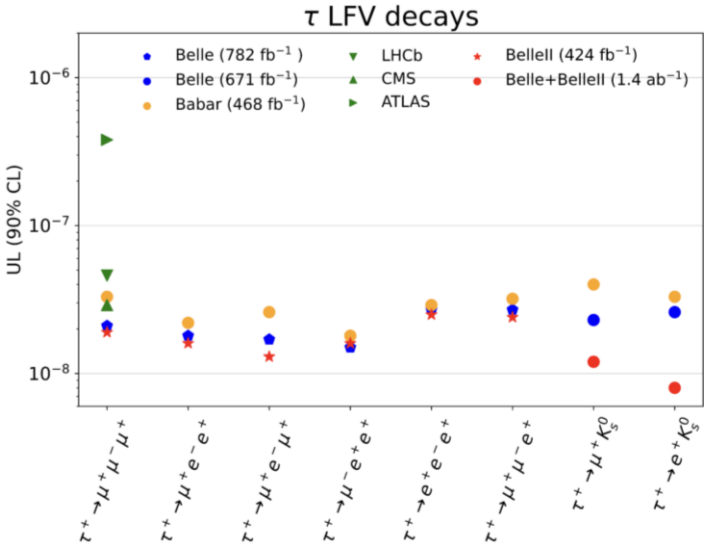
- Untagged method less powerful than traditional methods
- First τ analysis combining Belle and Belle II data, best limits!
- Published in JHEP: JHEP08(2025)092

First Search for τ→μγ with Belle II data (429fb^{-1})

- Similar but slightly larger upper limit than Belle

$$\mathcal{B}(\tau^- \to \mu^- \gamma)^{\rm exp} < 5.8 \times 10^{-8}$$

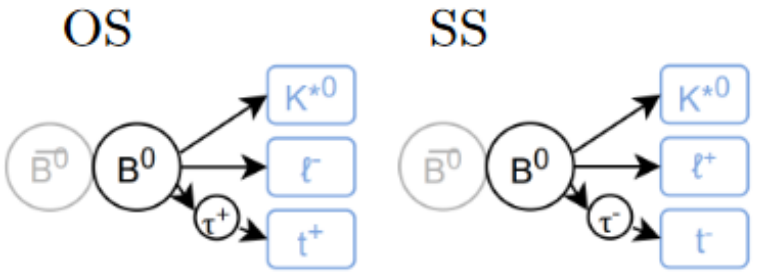
- To be published in JHEP

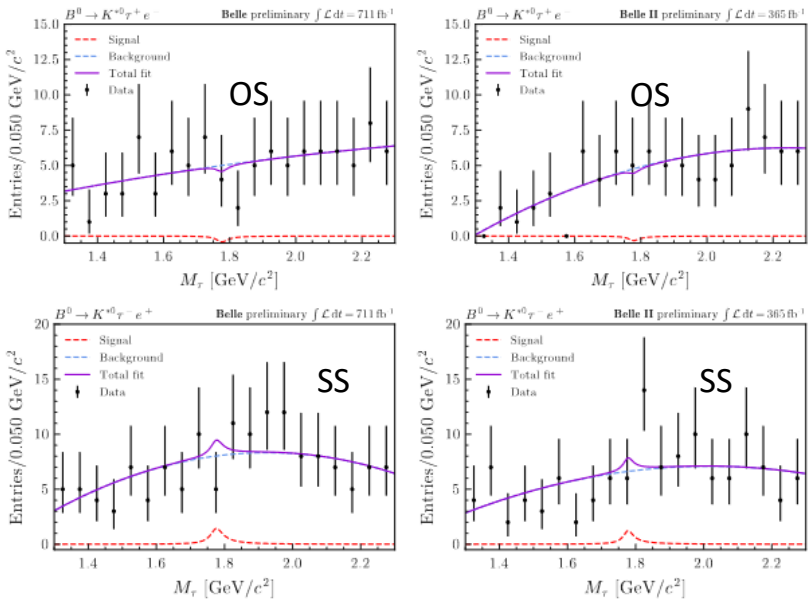


Forbidden Decays : B LFV decays

Search for B → K*τl with Belle + Belle II data

- Use hadronic tagging with Full event interpretation
- τ mass reconstructed from rest of event and tagged B
- 4 final states: same/opposite sign, e/μ
- First search at a B factory
- Published in JHEP: JHEP08(2025)184

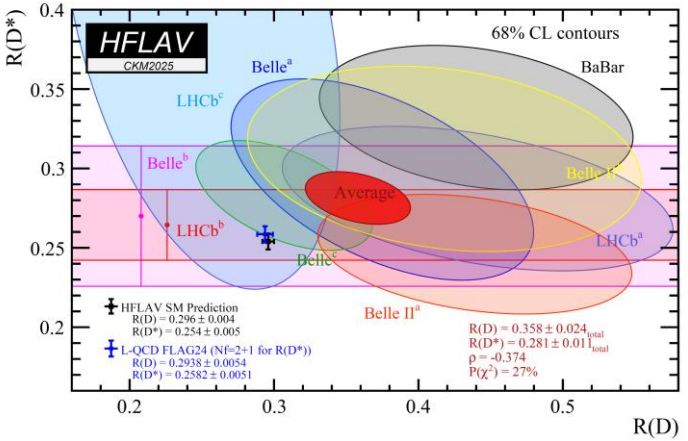




Precise test of LFU : R(D*) with Hadronic tagging

- R(D(*)) are deviated from the SM prediction ~3σ
  - Leptoquarks?

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

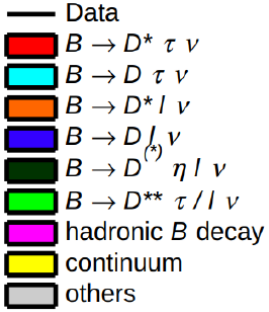


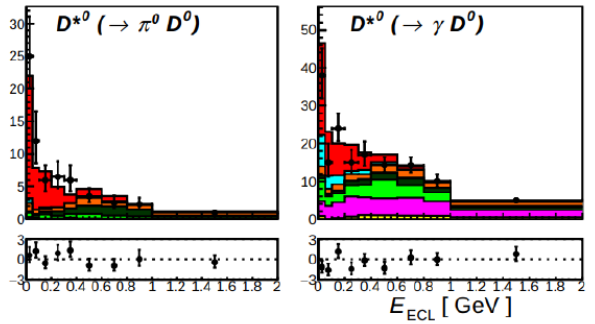
Updated result on R(D(*)) at Belle II (365fb^{-1})

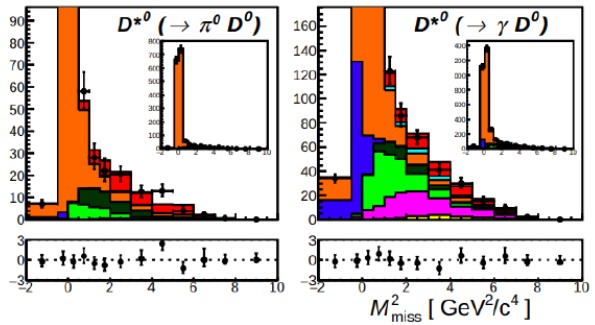
$$R(D) = 0.439 \pm 0.055(\text{stat}) \pm 0.045(\text{syst})$$
$$R(D^*) = 0.242 \pm 0.019(\text{stat}) \pm 0.016(\text{syst})$$

- Consistent with both WA and SM

SM
R(D) = 0.298 ± 0.004
R(D*) = 0.254 ± 0.005



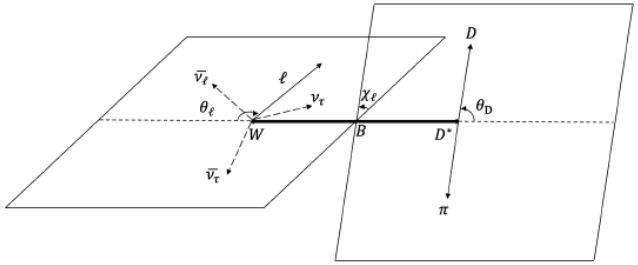


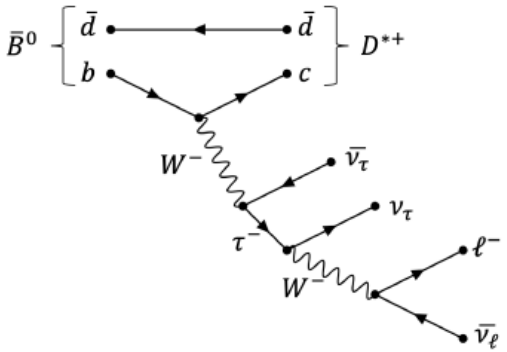


Calibration of BFs for the modes used for Hadronic tagging B→DX.

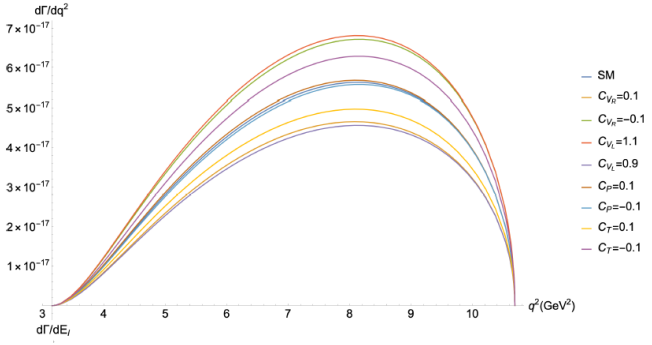
Theoretical studies on full angular analysis of B→D*τν, τ→lνν, D*→Dπ

- To discriminate new physics models, theoretical studies on full angular analysis is performed.
- Since there are four angular variables and three unobserved ν should be integrated out, this calculation is quite difficult and nobody performed before this.





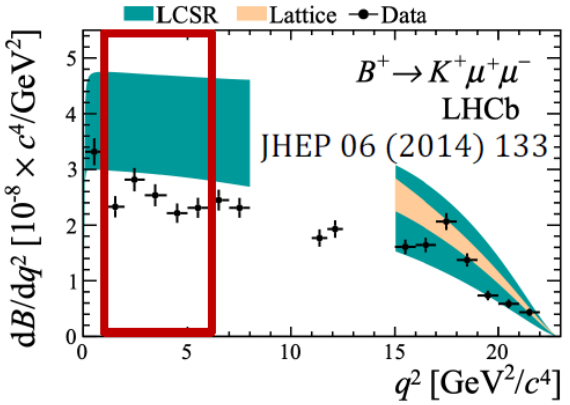
$$\frac{d\Gamma^{\tau}(\bar{B}\to D^*(\to D\pi)\tau^-(\to \ell\bar{\nu}_\ell\nu_\tau)\bar{\nu}_\tau)}{dwdE_\ell d\cos\theta_D d\cos\theta_\ell d\chi_\ell} = \frac{3G_F^2|V_{cb}|^2|\eta_{\rm EW}|^2 M_{D^*}\mathcal{B}(D^*\to D\pi)\mathcal{B}(\tau\to\ell\nu_\tau\bar{\nu}_\ell)}{16(4\pi)^5 M_B^2 M_\tau^6 |\vec{p}_D|^2}$$
$$\times \frac{|\vec{p}_{D^*}(w)||\vec{p}_\tau(w)|E_\ell}{\sqrt{1+r^2-2wr}}\Big\{ J_{1s}^{\tau}\sin^2\theta_D + J_{1c}^{\tau}\cos^2\theta_D$$
$$+ (J_{2s}^{\tau}\sin^2\theta_D + J_{2c}^{\tau}\cos^2\theta_D)\cos 2\theta_\ell$$
$$+ J_3^{\tau}\sin^2\theta_D\sin^2\theta_\ell\cos 2\chi_\ell$$
$$+ J_4^{\tau}\sin 2\theta_D\sin 2\theta_\ell\cos\chi_\ell + J_5^{\tau}\sin 2\theta_D\sin\theta_\ell\cos\chi_\ell$$
$$+ (J_{6s}^{\tau}\sin^2\theta_D + J_{6c}^{\tau}\cos^2\theta_D)\cos\theta_\ell$$
$$+ J_7^{\tau}\sin 2\theta_D\sin\theta_\ell\sin\chi_\ell + J_8^{\tau}\sin 2\theta_D\sin 2\theta_\ell\sin\chi_\ell$$
$$+ J_9^{\tau}\sin^2\theta_D\sin^2\theta_\ell\sin 2\chi_\ell\Big\}, \qquad (3.39)$$



Published in JHEP 04 (2025) 135

Precise test of LFU : $B \rightarrow X_s l^+ l^-$

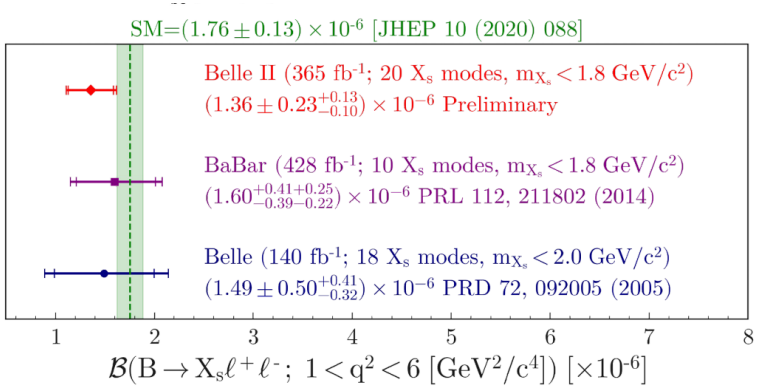
- LHCb results on $B \rightarrow K(*)\mu\mu$ show deficit compared with the SM prediction.
  - The SM prediction suffers from uncertainties due to form factors and charm loop calculations
  - These are not in the inclusive $B \rightarrow X_s l^+ l^-$
- Precise measurement of $B \rightarrow X_s l^+ l^-$ with Belle II ($365 fb^{-1}$)
  - Two times improvement on BF



$$\mathcal{B}(B \to X_s e^+ e^-) = \left(1.60 \pm 0.33^{+0.15}_{-0.11}\right) \times 10^{-6}$$
$$\mathcal{B}(B \to X_s \mu^+ \mu^-) = \left(1.13 \pm 0.33^{+0.11}_{-0.08}\right) \times 10^{-6}$$
$$\mathcal{B}(B \to X_s \ell^+ \ell^-) = \left(1.36 \pm 0.23^{+0.13}_{-0.10}\right) \times 10^{-6}$$

  - First measurement of LFU observable

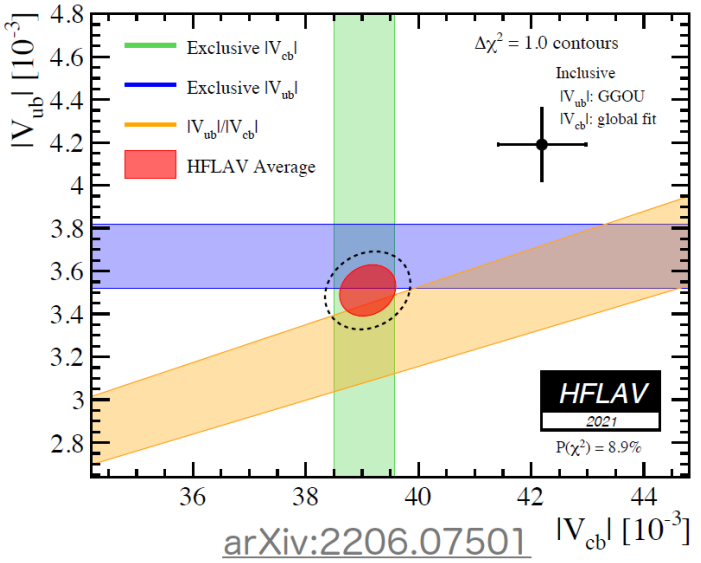
$$R(X_s) = \frac{\mathcal{B}(B \to X_s \mu^+ \mu^-)}{\mathcal{B}(B \to X_s e^+ e^-)} = 0.74 \pm 0.19 \pm 0.04$$



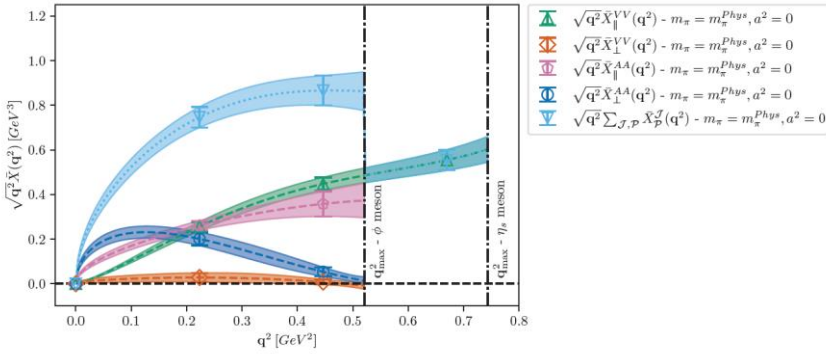
Consistent with the SM

Lattice QCD computations/dvlpmnts

- Form Factors
  - Uncertainties due to Form factors are very important to understand the physics in quark decays.
  - $B \rightarrow D^* l\nu$
  - $B \rightarrow \pi l\nu$
  - $B_s \rightarrow K l\nu$



- Inclusive decays
  - Differential decay rate of $Ds \rightarrow Xsl\nu$
  - Systematic effect in inclusive $b \rightarrow c$ computation
    - Tension between inclusive and exclusive determinations of both $|V_{cb}|$ and $|V_{cb}|$



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Other ongoing works

- Search for $\tau \rightarrow \mu\gamma$, $e\gamma$
- Search for LFV decays B → $\rho\tau l$, following similar strategy as B → $K^*\tau l$
- Search for B → $\tau\tau$ with hadronic tagging
- Measurement of B→$\tau\nu$ with semileptonic tagging
- Angular analysis of B→D(*)$\tau\nu$
- CP Violation in B→K$\pi\pi\gamma$ and B→X$s\gamma$

Plan for JFY2026

Studies

- LFU and LFV studies

B→τν with semileptonic tagging

Continue studies on R(D(*)) with hadronic tagging

Study on B→K(*)l+l-

B→ττ

B→ρτl

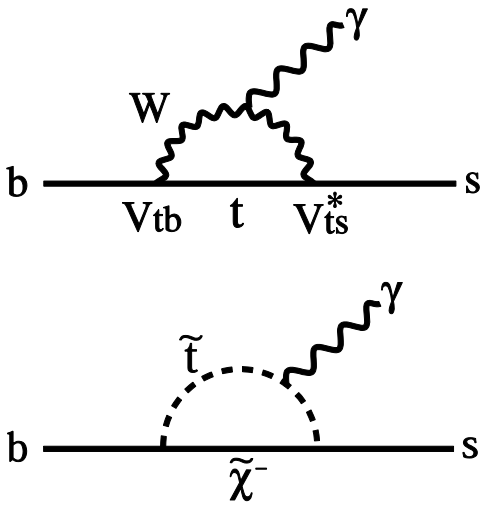
Search for τ→μμμ

Search for τ→μγ , eγ

- b→sγ

Photon polarization in B→Kππγ

CP violation in B→Kππγ and inclusive B→Xsγ



Joint Supervision

Shijie Wang from U-Tokyo studies photon polarization in B→Kππγ at Belle II under a supervision of Akimasa.

- In the SM, the photon is predominantly left-handed while new physics allows right-handed
- This measurement requires generator for MC simulation which should be implemented to EvtGen generator in Belle II software framework.

Emi already developed GamPola generator for this purpose.

Shijie is now visiting to IJClab for three months to implement the GamPola code to EvtGen under a supervision of Emi and Francois.

- Meeting dedicated on this subject was held in May 2026 at IJClab
- Weekly meeting is held.

Summary

- Achievements
  - Belle II LFU and LFV results with B mesons and τ leptons
  - Theoretical calculation on $B \rightarrow D^* \tau \nu$
  - Lattice QCD computation on form factors and inclusive decays

- Plan
  - Continues the studies on LFU and LFV
  - Photon polarization and CPV in $b \rightarrow s\gamma$
  - Generator development for $B \rightarrow K\pi\pi\gamma$

backup