[FLAV_06] Precise measurements and searches for forbidden decays of B mesons and tau leptons

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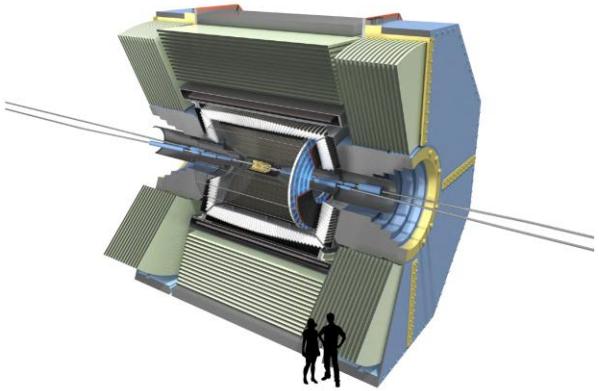
Justine Serrano (CPPM)

Takashi Kaneko (KEK)

Emi Kou (IJClab)

FLAV_03

- FLAV_06 is the successor of the FLAV_03 from 2017 to 2022
- FLAV_03
  - Title : Flavour physics and theoretical challenge for precision
  - PIs : Emi Kou (IJCLab) , Takashi Kaneko (J:KEK)
    - Two theorists led the project but joint effort with experimentalists was the key for this project. Exp + Pheno + Lattice QCD
  - Topics : Mainly on Flavor Physics at Belle (II)
    - Semileptonic B decays and Lattice QCD
    - Time dependent CPV in hadronic b→s transitions
    - Radiative B meson decays
    - ϕ_3 determination using dispersion relation method
    - Lepton flavor violation in τ decays
    - Dark sector and axion searches



- Let me report the activities in FLAV_03 in 2022

The team

- 6 persons from French side
- 8 persons from Japanese side

French Group			Japanese Group		
name (Family name, First name)	**title**	**lab.[2]**	**name** (Family name, First name)	**title**	**lab.[2]**
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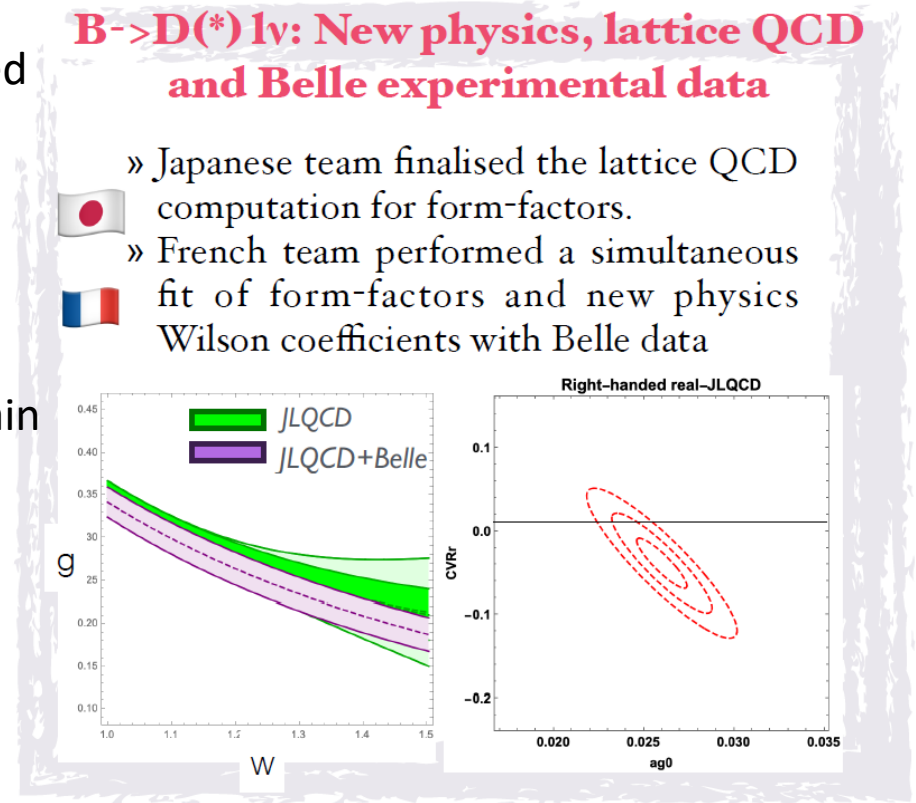
F. Le Diberder	Prof.	IJCLab -Belle II	K. Hayasaka	Prof.	Belle II- Niigata
T. S. Lau	Dr.	IJCLab -Belle II	S. Hashimoto	Prof.	Theory-KEK
T. Kapoor	Mr.	IJCLab -Theory	A. Ishikawa	Assoc. Prof.	Belle II -KEK
F. Callet	Mr.	Aix-Marseille University	H. Kakuno	Prof.	Belle II -TMU
			M. Nakao	Prof.	Belle II -KEK
			S. Nishida	Assoc. Prof.	Belle II -KEK

Activity Report of 2022:B→D(*)lν

- B→D(*)lν result by Belle was slightly deviated by Lattice QCD computation.
- T. Kaneko and S. Hashimoto (KEK) finalized the computation of form factors.
- E. Kou (IJClab) performed the fit to new physics Wilson coefficients with form factor by JLQCD and Belle data to constrain on right handed currents
  - ~2σ deviation from the SM
- The paper draft is preparing.



T. Kaneko, S. Hashimoto et al: arXive:2305.xxxxx

Activity Report of 2022:ALPs

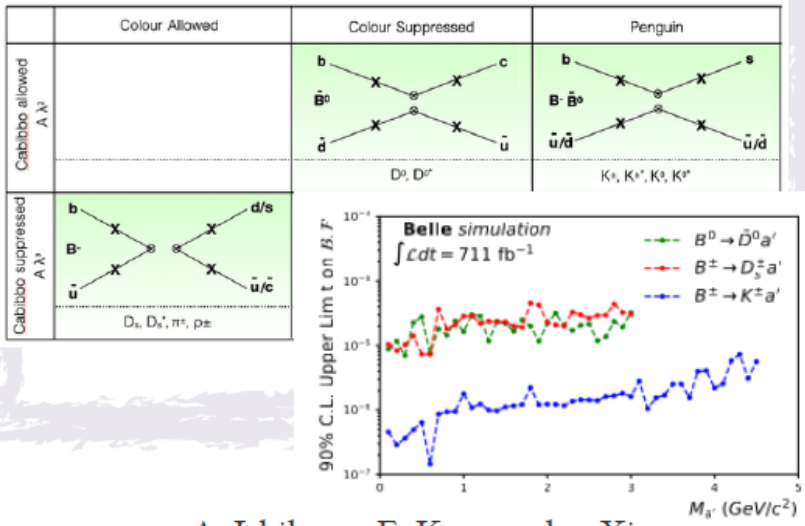
- ALPs couplings to quarks can be searched with B meson decays, B→Xa, X=π, K^+, D^0, Ds
  - Potential sensitivities calculated by E. Kou (IJClab)
  - MC studies at Belle II by T. S. Lau (IJClab) together with E. Kou (IJClab) and AI (KEK)
- The draft paper is preparing.

AI (KEK) visited IJClab to discuss about ALPs with E. Kou and T. S. Lau

ALPs: Production via annihilation and its search at Belle II

» French team proposed a new production mechanism of Axion-Like particle (ALPs).

» Japanese team performed a sensitivity study with Belle (II) Monte Carlo data.



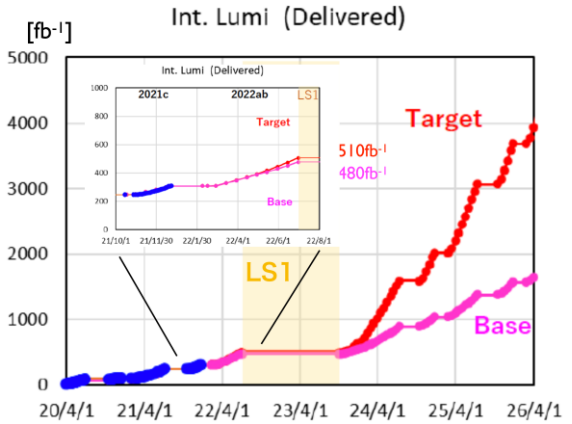
A. Ishikawa, E. Kou, et al: arXive:2305.xxxxx

People Exchanges in 2017-2022

- Jointly supervised students
  - Melissa Faur (ENS-Paris, with T. Kaneko)
  - Flavien Callet (ENS-Paris-Saclay, with S. Hashimoto)

- Workshop organization and participation
  - Physics Week 2018 (KEK), 2019 (KEK) and 2020 (remote)
  - KEK-FF 2023 (KEK)

FLAV_06 Proposal



- 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 and T. Kaneko
    - Belle II will collect more data than Belle in
  - Topics : Flavor Physics at Belle (II)
    - Focusing on precise measurements of lepton flavor universality (LFU) and search for forbidden decays via lepton flavor violation (LFV)
    - Other flavor physics studies pursued at previous program and newly covered analyses included

The Team

- 12 persons from French side (was 6)
- 12+1 persons from Japanese side (was 8)

Stronger team!

French Group			Japanese Group		
name (Family name, First name)	**title**	**lab.**[2]	**name** (Family name, First name)	**title**	**lab.**[32]
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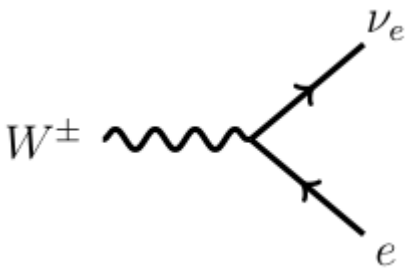
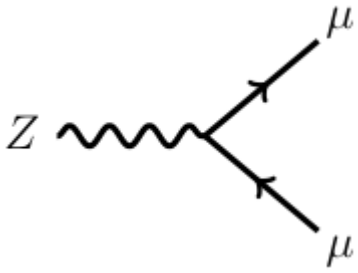
Lautenbach Klemens	Dr	CPPM/IN2P3	Koji Hara	Assoc.Prof	KEK
Bertacchi Valerio	Dr	CPPM/IN2P3	Kiyoshi Hayasaka	Prof	Niigata
Leboucher Robin	Mr	CPPM/IN2P3	Shoji Hashimoto	Prof	KEK
Thaller Arthur	Mr	CPPM/IN2P3	Takashi Kaneko	Assoc.Prof	KEK
Lemettais Clotilde	Mr	CPPM/IN2P3	Taichiro Koga	Assist. Prof	KEK
Kou Emi	Dr	IJCLab/IN2P3	Yuxin Liu	Mr	Sokendai
Martens Aurélien	Dr	IJCLab/IN2P3	Yu Nakazawa	Dr	KEK
Lediberder Francois	Dr	IJCLab/IN2P3	Shohei Nishida	Assoc.Prof	KEK
Tejhas Kapoor	Mr	IJCLab/IN2P3	Cyrille Praz	Dr	KEK
Lau Tak Shaun	Dr	IJCLab/IN2P3	Yo Sato	Dr	KEK
			+ Kenta Uno,	Assist Prof,	KEK

Lepton Flavor Universality

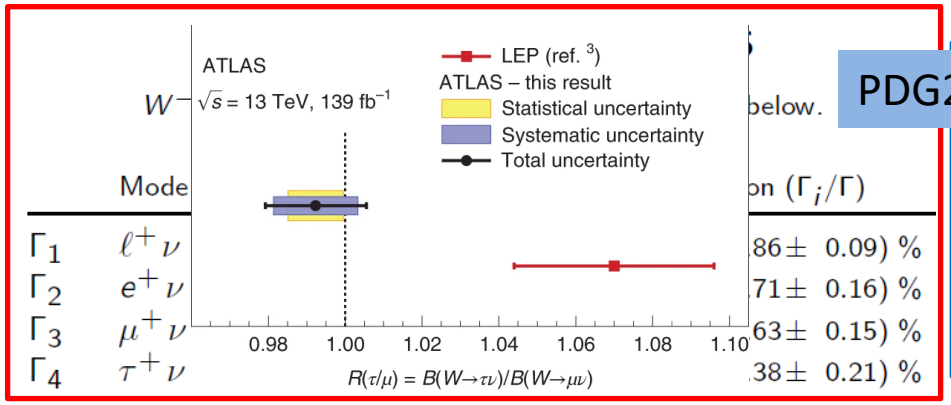
- LFU holds in the SM
  - Couplings to leptons are universal
  - The difference of decay rate/distribution only from lepton masses.
  - LFU is tested with many decays
    - Charged current : ~2% in W decays
    - Neutral current : ~0.3% in Z decays



$$\frac{\mathcal{B}(W^+ \to \mu^+\nu_\mu)}{\mathcal{B}(W^+ \to e^+\nu_e)}$$



$$\frac{\mathcal{B}(Z \to \mu^+\mu^-)}{\mathcal{B}(Z \to e^+e^-)}$$



PDG2022

Z DECAY MODES

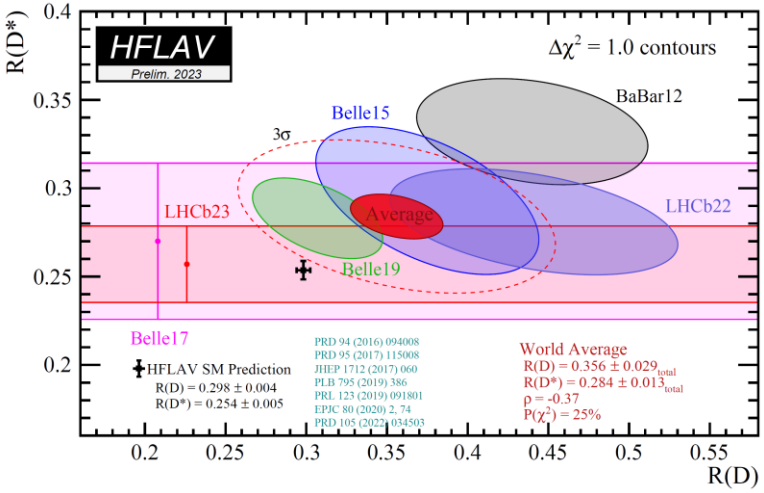
	Mode		Fraction (Γ_i/Γ)
Γ_1	e^+e^-	[a]	(3.3632 ± 0.0042) %
Γ_2	$\mu^+\mu^-$	[a]	(3.3662 ± 0.0066) %
Γ_3	$\tau^+\tau^-$	[a]	(3.3696 ± 0.0083) %
Γ_4	$\ell^+\ell^-$	[a,b]	(3.3658 ± 0.0023) %

B→D(*)τν with Hadronic tagging

- LFU violation in B→D(*)τν decays is seen at 3.2 σ level
  - If observed, this is clear signal of new physics.
    - Leptoquark, flavorful W'

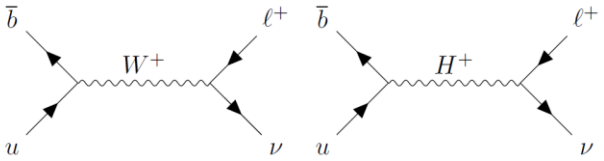
$$R(D^{(*)}) = \frac{BF(B \to D^{(*)} \tau \nu_\tau)}{BF(B \to D^{(*)} l \nu_l)}$$

l=e,μ



- R(D) and R(D*) with hadronic tagging (T. Koga, K. Uno, K. Hara)
  - Sensitivity similar to or better than Belle
- Hadronic tagging calibration (IJClab)
- Lattice QCD provide R(D) and R(D*) pure SM predictions (T. Kaneko)

$B^+ \to \tau\nu$ and $B^+ \to \mu\nu$



- Proceeds via annihilation : helicity suppressed
  - Quark contents are different from $b \to c\tau\nu$
- SM and 2HDM with Z_2 symmetry contributions hold LFU
  - The BF ratio is constant (only dependent on masses)

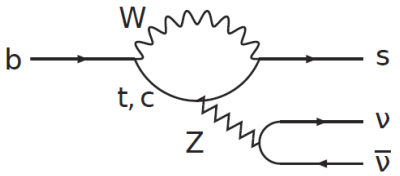
$$R_{\rm pl} = \frac{\mathcal{B}(B^+ \to \tau^+\nu_\tau)}{\mathcal{B}(B^+ \to \mu^+\nu_\mu)} = 222$$

- If flavor non-universal new physics in $b \to c\tau\nu$ also affected to $b \to u\tau\nu$, the ratio differs from 222.
- Since both decays are not observed yet, try to observe the $B^+ \to \tau\nu$ decays with semileptonic tagging (T. Fillinger and AI (KEK))

- Since the decay constant f_B is important to compare the measured BF with theoretical prediction, we will consult with lattice QCD colleagues.

  - Within the SM, |Vub| can be extracted.

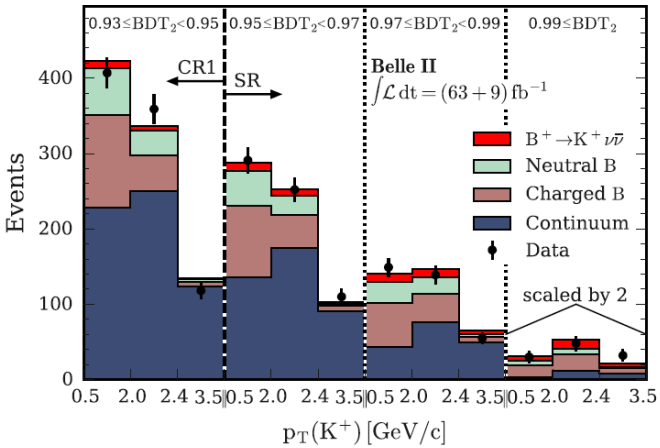
B→Kνν

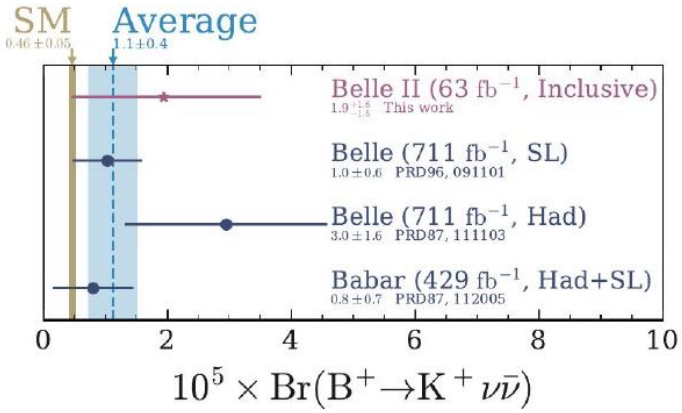


- B→Kμμ anomaly was gone
- However LFU violating new physics contribution to neutrino flavor sector could be different from charged lepton flavor sector (or dark matter contribution)

- Inclusive tagging with machine learning with 63fb^{-1} at Belle II gave better sensitivity per luminosity than hadronic tagging at Belle

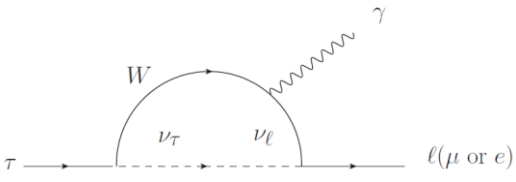
- Update with larger luminosity to observe the decay (C. Praz)

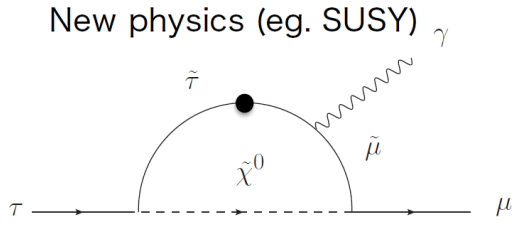




Lepton Flavor Violation

- LFV never occurs within the SM
  - Even considering the neutrino mixing, LFV should be tiny enough not to observed at on-going experiments.
  - Within new physics, the branching fractions could be observed level
    - SUSY
    - Leptoquarks
    - Flavorful W' and Z'
  - LFV could be associated with LFU violation in new physics
- At Belle and Babar, many LFV decays are searched
  - τ decays
  - B decays

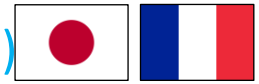
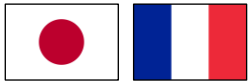
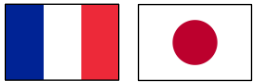




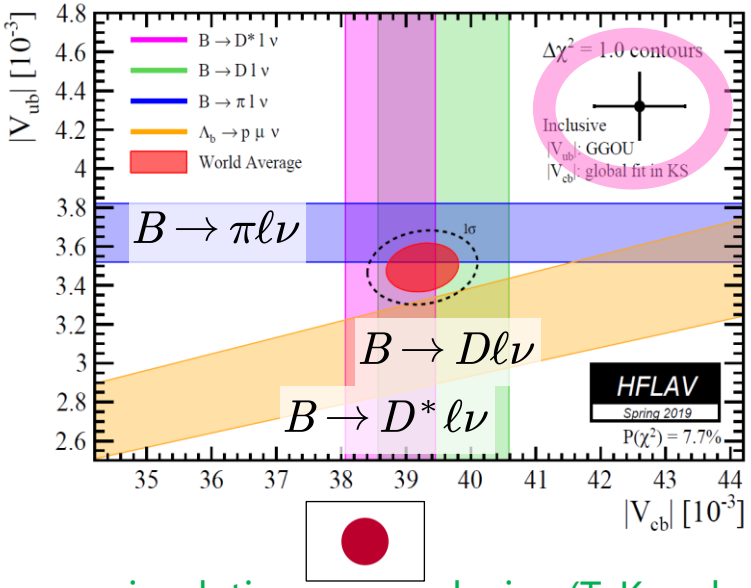
Lepton Flavor Violating τ decays

- CPPM already started analyses on several LFV τ decays 
  - Japanese group has deeper knowledge since these were performed at Belle (K. Hayasaka (Niigata), K. Uno (KEK)) 
- Phenomenological collaboration
  - impact of the different LFV channels and of their correlations with LFU measurements on new physics models (CPPM, IJClab) 
- LFV τ decay studies at upgraded SuperKEKB with polarized electron beam (A. Martens (IJClab)) 

Other Important Studies

- Lattice QCD for CKM matrix and α_s(T. Kaneko, S. Hashimoto, F. Callet) 
- $\phi_2(\alpha)$ and $\phi_3(\gamma)$ measurements (Y. Nakazawa, E. Kou, AI) 
- Full angular analysis of B→K$\pi\pi\gamma$ (T. S. Lau, E. Kou, AI) 
- Inclusive b→sγ and b→sl^+l^- decays (Y. Liu, Y. Sato, AI) 
- Time dependent CPV in b→sqq (E. Kou, K Hara) 
- Dark sector and ALPs searches (E. Kou, S. Nishida, AI) 

Lattice QCD



more simulations on exclusive (T. Kaneko)

- $B \to \pi \ell \nu$ towards Belle II precision (5% → 2%)
- $B \to D^{(*)} \ell \nu$ @ large recoils ($w \leq 1.1 \to 1.3$)

⇒ more detailed comparison w/ experiments

⇒ precise & pure SM value of $R(D^{(*)})$

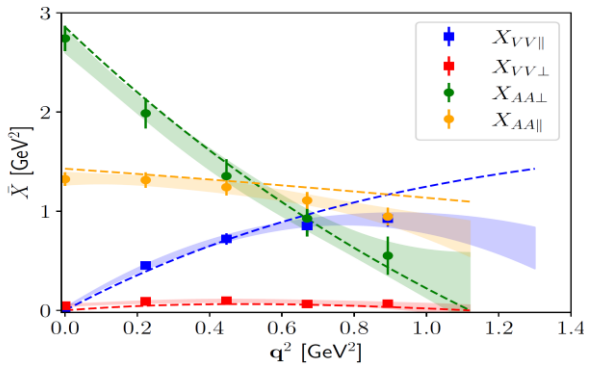
- also $B_s \to K \ell \nu$

inclusive decays on the lattice (S. Hashimoto)

- developing new method
- direct comparison w/ exclusive analysis

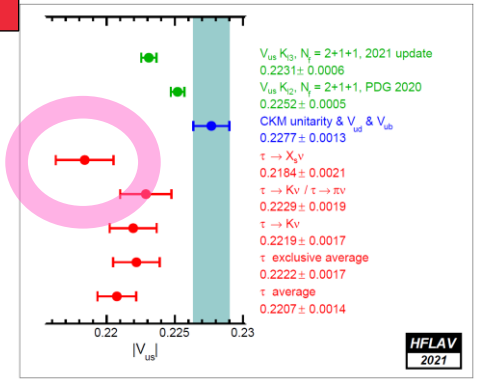
⇒ hint for $|V_{\{u,c\}b}|$ tension?

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3} |V_{cb}|^2 \sqrt{q^2}\, \bar{X}(q^2)$$



application to τ inclusive decay (F. Callet))

⇔ tension in $|V_{us}|$ w/ exclusive K, τ decays



Internship at KEK under Prof Shoji Hashimoto in the period of Feburary to August 2023.

Full angular analysis of B→Kππγ

- In the SM, photon in b→sγ is predominantly left-handed.
- New physics with right-handed currents alters the polarization
  - Right handed W' Emi Kou et al. "Photon Polarization in the $b \to s\,\gamma$ processes in the Left-Right Symmetric Model", *JHEP*, 12 102, 2013
  - SUSY K. Hidaka, H. Eberl, E. Ginina, and A. Ishikawa, "Imprint of SUSY in radiative B-meson decays", *Phys.Rev.D*, 104 7, 075025, 2021
- Angular analysis of B→Kππγ is sensitive to photon polarization.
  - A_{UD} was performed at LHCb (efficiency correction?), however only limited angular information used.
- Full angular analysis will be performed to extract photon polarization λ and J function
  - Theoretical calculation (E. Kou (IJClab)
  - Implementation of the generator model in EvtGen (T. S. Lau and E. Kou)
  - started the MC study (T. S. Lau, E. Kou (IJClab) and AI (KEK))

$$\frac{d\Gamma}{ds_{13}ds_{23}d\cos\theta} \propto \frac{1}{4}|\vec{J}|^2(1+\cos^2\theta) + \lambda\frac{1}{2}Im\left[\vec{n}\cdot(\vec{J}\times\vec{J}^*)\right]\cos\theta$$

EK, Le Yaouanc, A.Tayduganov, PRD83 ('11)

Summary

- FLAV_03 in 2017-2022
  - Under the COVID-19 situation, people exchange was strongly limited
  - From 2022, people exchange restarted and results of joint studies are bearing fruit.
- FLAV_06 Proposal
  - Belle II will collect more data than Belle in 2024
  - Focusing on LFU and LFV decays at Belle (II)
    - LFU violation seen with 3.2s deviation in R(D) and R(D*)
    - LFV could associated with LFU violation.
  - Also other important flavor studies at Belle II will be performed.

backup