



[FJPPN-FLAV_06]

Precise Measurements and Searches for Forbidden Decays of B mesons and tau leptons

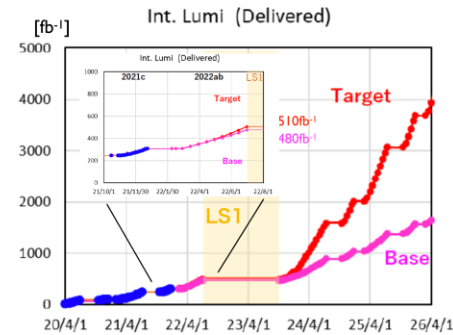
Akimasa Ishikawa (KEK) 



Justine Serrano (CPPM) 

Takashi Kaneko (KEK) 

Emi Kou (IJCLab) 

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)
 - Belle II will collect [more data than Belle](#) in JFY2024
- 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 such as precise measurements of [CPV](#) and [angular distributions](#) included

The Team

- 12 persons from French side
- 12 persons from Japanese side



Strong team!

	 French Group			 Japanese Group		
	name (Family name, First name)	title	lab.²	name (Family name, First name)	title	lab.²
PIs: Members:	Serrano Justine	Dr	CPPM/IN2P3	Akimasa Ishikawa	Assoc.Prof.	KEK
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	Lisovskyi Vitalii	Dr	CPPM/IN2P3	Koji Hara	Assoc.Prof	KEK
	Bertacchi Valerio	Dr	CPPM/IN2P3	Kiyoshi Hayasaka	Prof	Niigata
	Consigny Isaac	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	Assist Prof.	KEK
	Lediberder Francois	Dr	IJCLab/IN2P3	Shohei Nishida	Prof	KEK
	Tejhas Kapoor	Mr	IJCLab/IN2P3	Kenta Uno	Assist Prof	KEK
	Lau Tak Shaun	Dr	IJCLab/IN2P3	Yuta Takinami	Mr	Niigata

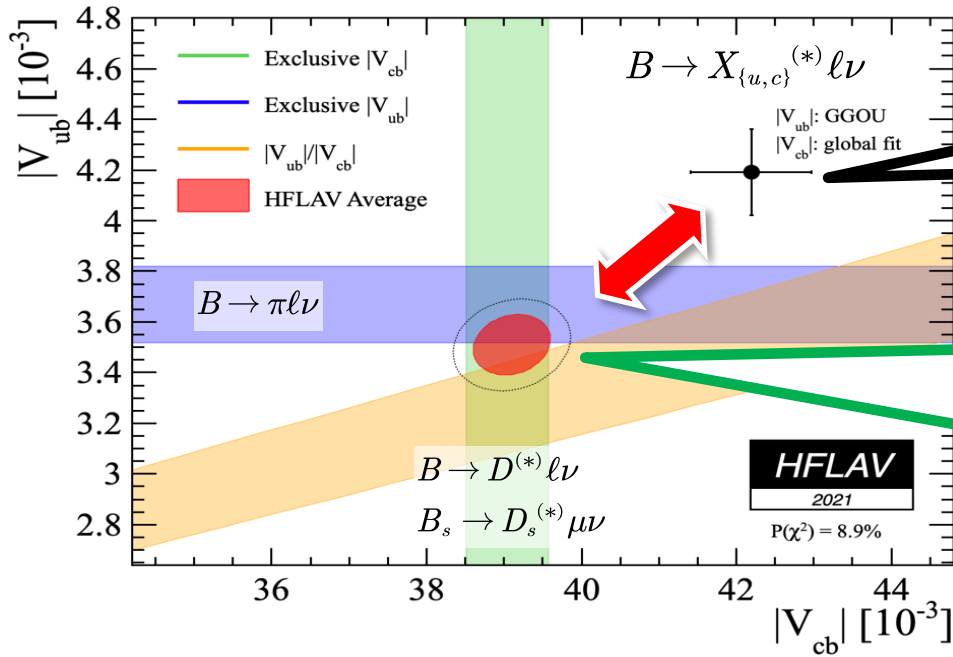
Report on Activities in JFY2023

Meetings and Joint Efforts

- Three regular meetings
 - General one
 - Focusing on semileptonic decays and τ LFV decays
- One Face-to-Face lunch meetings at B2GM
- Organization of Belle II Physics Week 2023 by S. Hashimoto and T. Kaneko

- A. Ishikawa visited IJClab to discuss about interference effect in $B \rightarrow \rho\rho$ with E. Kou
- Jointly supervised student
 - Flavien Callet  : Internship at Shoji Hashimoto 

a long-standing tension in CKM elements



$\geq 8\%$, 3σ tension for more than 10 years ...

inclusive decays

$$B \rightarrow X_c \ell \nu = D \ell \nu + D^* \ell \nu + D^{**} \ell \nu + \dots$$

exclusive decays

$$B \rightarrow D \ell \nu, D^* \ell \nu, D^{**} \ell \nu, \dots$$

$$\langle D^* | V_\mu | B \rangle = \varepsilon_{\mu\nu\rho\sigma} \epsilon^{*\nu} v^\rho v'^\sigma h_V, \dots$$

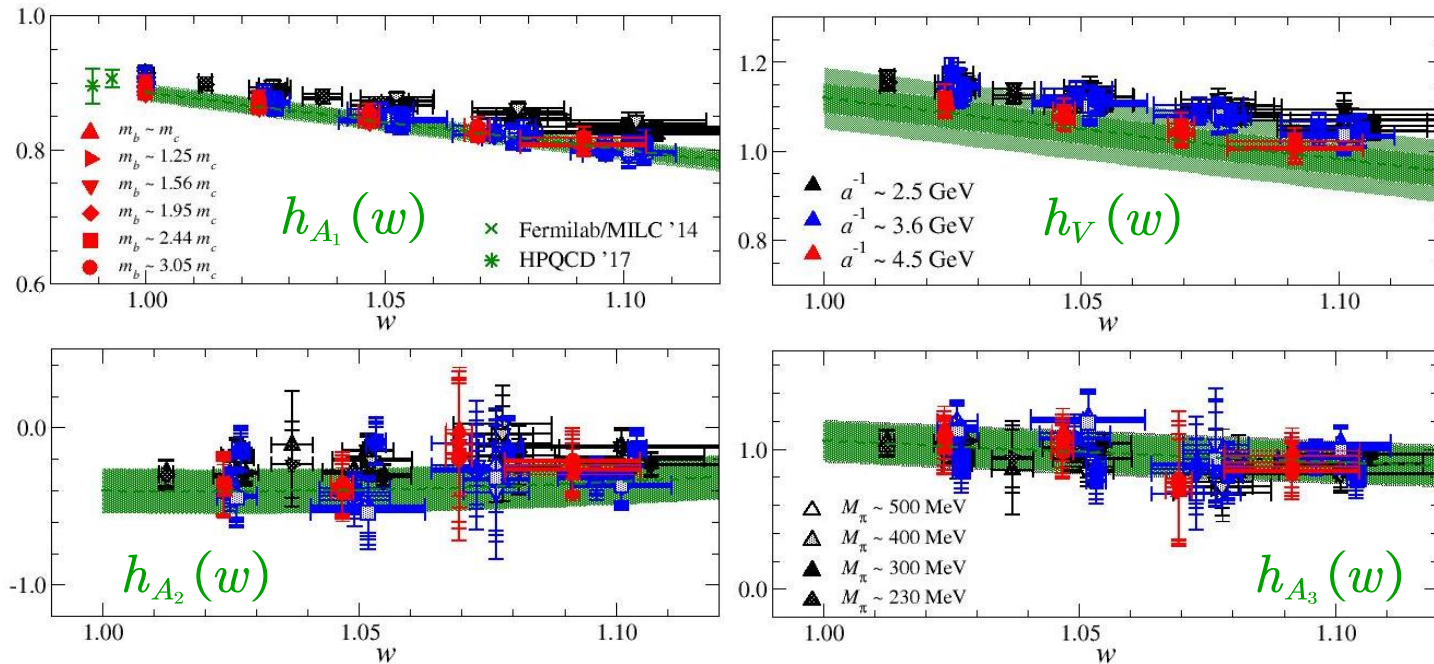
4 form factors (FFs) : $h_V, h_{A1}, h_{A2}, h_{A3}$

\Rightarrow non-perturbative QCD effects

- Crivellin+ '18 : not due to new physics? \Leftrightarrow new tension w/ $B \rightarrow \tau \nu$, too large $\Gamma(Z \rightarrow b\bar{b})$
- th and/or exp't uncertainties haven't been fully understood : largest th error from FFs
- this project \Rightarrow a recent calculation PRD 109 (2024) 074503, "Editors' Suggestion"



JLQCD collaboration's calculation of all FFs



- clean formulation w/ chiral symmetry \Rightarrow control of systematic uncertainties
- powerful Fugaku computer \Rightarrow high statistics simulations

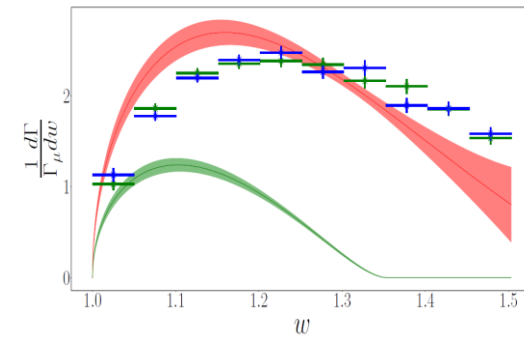
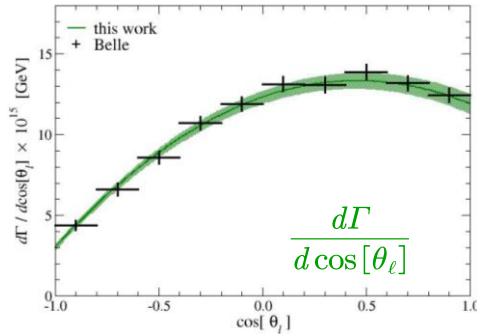
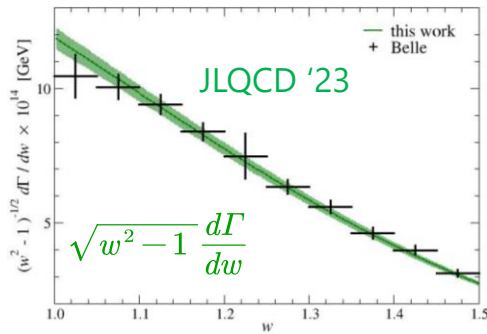
\Rightarrow precise & reliable calculation of all FFs



Implications...



differential decay rate consistent w/ Belle



HPQCD not yet published
 inconsistent w/ exp even w/ NP

$|V_{cb}|$ tension remains unsolved ...

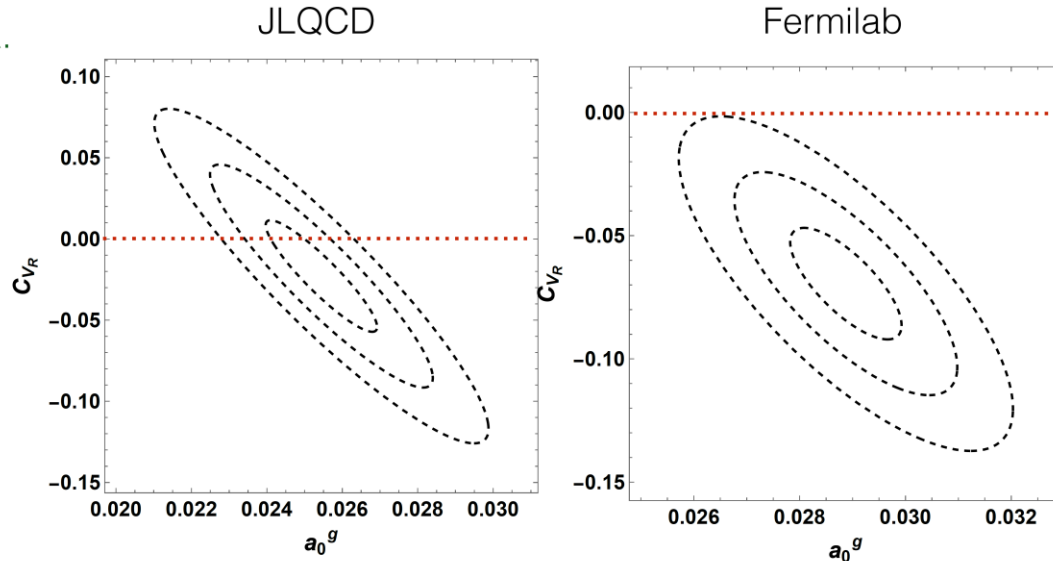
- $|V_{cb}| \times 10^3 = 39.19(90) \Rightarrow$ very consistent w/ previous exclusive determinations
- possible sources? \Rightarrow “Belle II Physics Week 2023” w/ many theorists & experimentalists
 - + a possible bias called “D’Agostini effects” due to strong correlations of exp’tal data
 - + unsafe Bayesian analysis to compare theoretical and experimental data
 - + or else?

New physics search with $B \rightarrow D^* l \nu$ in light of new lattice data

- JLQCD has published **lattice QCD results** on the $B \rightarrow D^*$ Form Factors. Thus, we are **ready to move to BSM fit!**
- We performed toy study of the unbanned maximum likelihood method of Belle data to new physics models including the lattice data and observed some tension in **Right-handed model is intriguing.**

T. Kappor, Z.R. Huang, E.K.
arXiv:2401.2401.11636

$C_{VR} \neq 0$
⇒ New physics!



Measurement of $R(D^*)$ with Hadronic tagging

- $R(D^{(*)})$ is deviated from the SM prediction about 3σ
 - Leptoquarks?

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



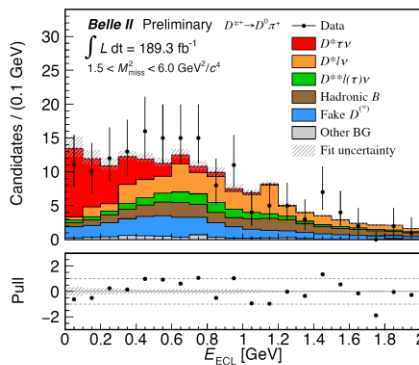
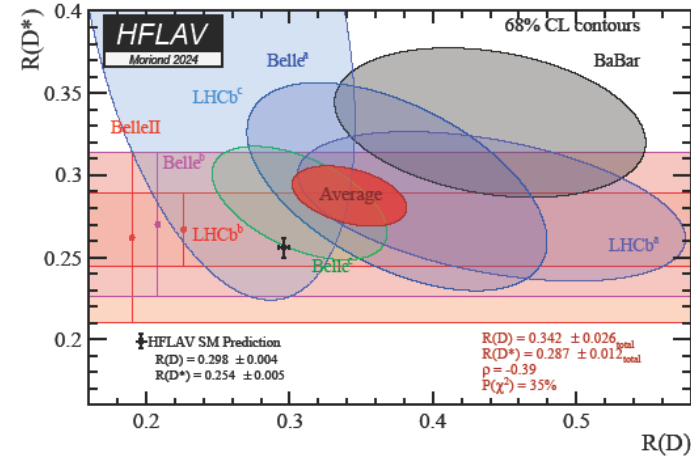
First result on $R(D^*)$ at Belle II was submitted to PRD

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

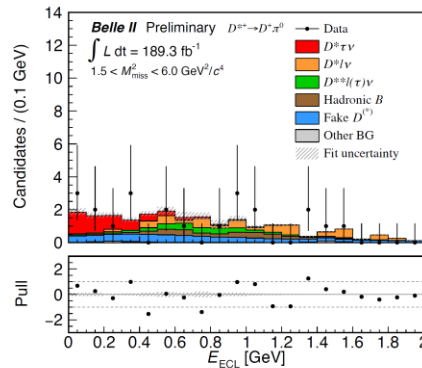
$$0.254 \pm 0.005 (\text{SM})$$

- Consistent with both WA and SM

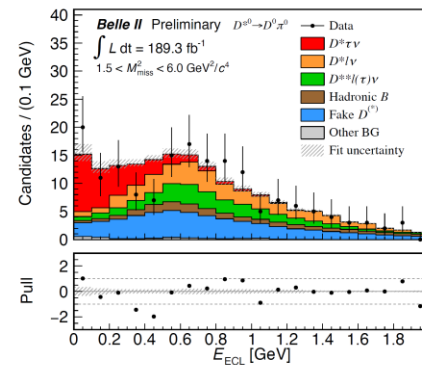
<https://arxiv.org/abs/2401.02840>



(a)



(b)



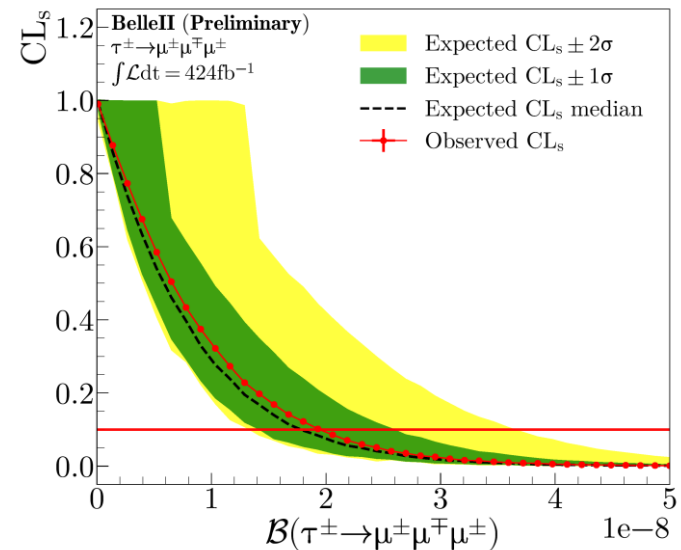
(c)



Calibration of BFs for the modes used for Hadronic tagging $B \rightarrow D^{(*)} KK^{(*)}$, $D^{(*)} D_s$

Search for $\tau \rightarrow \mu\mu\mu$

- $\tau \rightarrow \mu\mu\mu$ decay is the cleanest LFV τ decay mode
 - Almost background free
 - Sensitive to LFV Z' etc
- Search at Belle II
 - 424fb^{-1}
 - Smaller than Belle 782fb^{-1}
 - Better selection to maximize the sensitivity
 - untagged
- Result
 - $< 1.9 \times 10^{-8}$
 - Better than Belle 2.1×10^{-8}
 - Submitted to PRD
 - <https://arxiv.org/abs/2405.07386>



Other Important Topics



$B \rightarrow DK, D \rightarrow K_s K \pi$ towards ϕ_3

- The ϕ_3 ($\sim \arg(-V_{ub}^*)$) is the second least precisely measured out of 3 angles and 3 sides.
 - Adding **new D decay modes** is crucial to improve
- Combined analysis of Belle (771fb⁻¹) and Belle II (362fb⁻¹)
- Published in JHEP [JHEP 09 \(2023\) 146](https://arxiv.org/abs/2403.02590)



Time dependent CPV in $B \rightarrow J/\psi K_s$ and $B \rightarrow K_s K_s K_s$

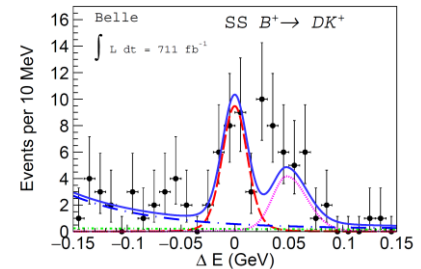
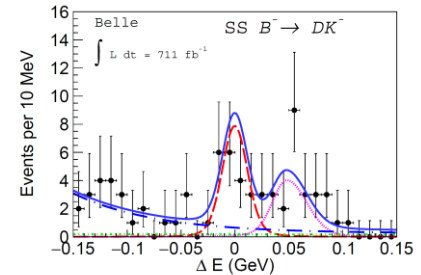
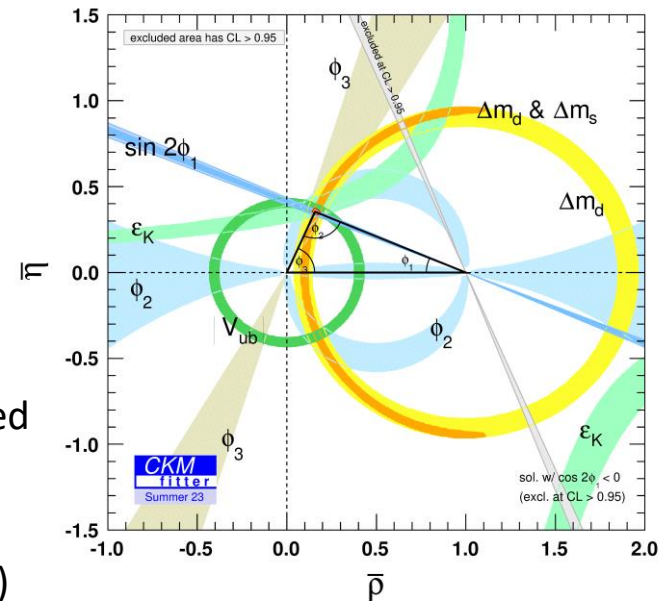
- Precise measurements of ϕ_1 in $b \rightarrow ccs$ and ϕ_1^{eff} in $b \rightarrow sss$
- Both 362 fb⁻¹
- Accepted for publications in PRD <https://arxiv.org/abs/2403.02590>



Sensitivity study for ALPs in B decays

- Exp+Pheno collaboration
- Published in PRD

<https://journals.aps.org/prd/abstract/10.1103/PhysRevD.109.016008>



Plan for JFY2024

Studies

- LFU and LFV studies



$B \rightarrow \tau \nu$ with semileptonic tagging



Continue studies on $R(D^{(*)})$ with hadronic tagging



Theoretical studies on full angular analysis of $R(D^{(*)})$



Study on $B \rightarrow K l^+ l^-$



Search for $B \rightarrow X s \nu \nu$



Search for $B \rightarrow \tau l X$ ($X = K^*, \rho$)



Search for $\tau \rightarrow \mu \gamma$



Search for $\tau \rightarrow l + \text{missing}$ (LFV with dark sector mediator)



Search for $\tau \rightarrow e l l$



Search for $\tau \rightarrow l K s$

- Other topics




Time dependent CPV in $B \rightarrow \rho \rho$ and extraction of ϕ_2



Hadronic τ decays (Next Page)

$\tau \rightarrow \pi \pi^0 \nu$ and $\tau \rightarrow \pi \pi^+ \pi \pi^0 \nu$ processes for fundamental QCD test

 IJCLab: Belle II data analysis to measure the $\tau \rightarrow \pi \pi^0 \nu$ process to estimate the Hadronic Vacuum polarisation, important for muon $g-2$ (PhD Thesis of F. Callet).

 Niigata University: Belle II data analysis to measure the $\tau \rightarrow \pi \pi^+ \pi \pi^0 \nu$ process, sensitive to the second class current (Master Thesis of Y. Takinami).

- Both processes involves π^0 which is a big challenge for Belle II experiment. We will tackle this problem within this French-Japan collaboration.

- [Mini-workshop dedicated on tau lepton](#) will be held at IJCLab



Summary

- Achievements
 - Three meetings and one lunch meeting
 - Study of semileptonic decays
 - Papers
 - Lattice QCD and Pheno studies using Belle results on $B \rightarrow D^* l \nu$: [PRD Editors' Suggestions](#)
 - Most stringent limit on LFV decays $\tau \rightarrow \mu \mu \mu$
 - Measurement of $R(D^*)$
 - $B \rightarrow DK, D \rightarrow K_s K \pi$ towards ϕ_3
- Plan
 - Continues the studies with the data to be collected at Belle II in JFY2024
 - LFU and LFV decays at Belle (II)
 - Also, other important flavor studies at Belle II will be performed.
 - Tau mini-workshop will be held in IJClab
 - Regular meetings will be held remotely or face-to-face at B2GM

backup