



[FJPPN-FLAV\_06]

# Precise Measurements and Searches for Forbidden Decays of B mesons and Tau leptons

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2025 joint workshop of FKPPN and TYL/FJPPN

# 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 central to this project: Exp + Pheno + Lattice QCD
- 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** included

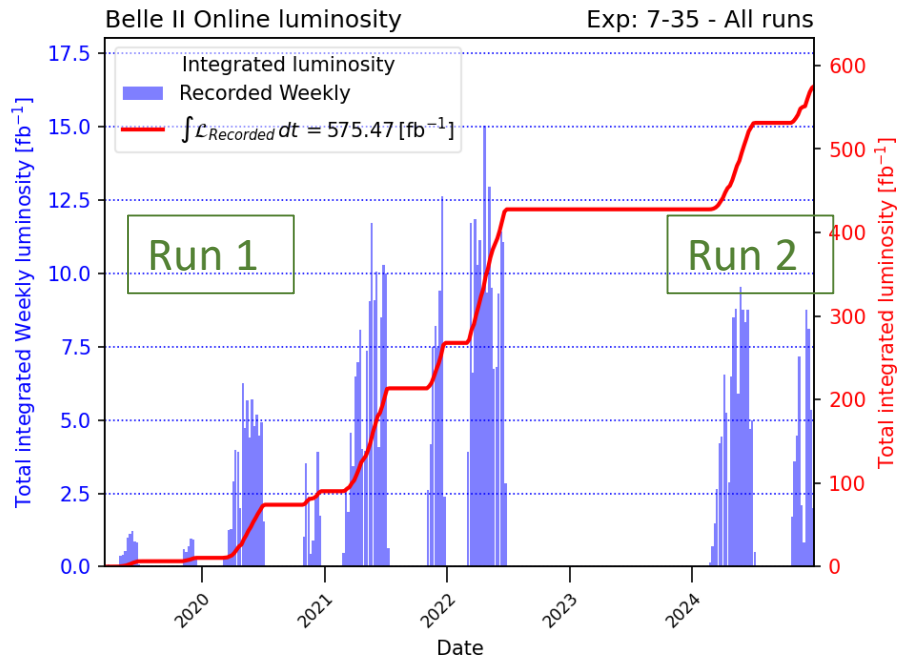
# The team

- 14 persons in France, 14 persons in Japan

|                                    |         |  French Group |                      |                   |  Japanese Group |                    |                    |          |
|------------------------------------|---------|--|----------------------|-------------------|--|--------------------|--------------------|----------|
|                                    |         | name<br>(Family name, First name)  | title                | lab. <sup>2</sup> | name<br>(Family name, First name)  | title              | lab. <sup>32</sup> |          |
| <b>PIs:</b><br><br><b>Members:</b> | e-mail: | Justine Serrabi  | Dr                   | CPPM/CNRS         | Akimasa Ishikawa   | Assoc.Prof.        | KEK                |          |
|                                    |         |  |                      |                   | e-mail:  |                    |                    |          |
|                                    |         |  | Giampiero Mancinelli | Dr                | CPPM/IN2P#   | Tristan Fillingier | Dr                 | KEK      |
|                                    |         |  | Vitalii Lisovskyi    | Dr                | CPPM/IN2P3   | Koji Hara          | Assoc.Prof         | KEK      |
|                                    |         |  | Clotile Lemettais    | Ms                | CPPM/IN2P3   | Kiyoshi Hayasaka   | Prof               | Niigata  |
|                                    |         |  | Isaac Consigny       | Mr                | CPPM/IN2P3   | Shoji Hashimoto    | Prof               | KEK      |
|                                    |         |  | Mattia Marfoli       | Mr                | CPPM/IN2P3   | Hidekazu Kakuno    | Prof               | TMU      |
|                                    |         |  | Emi Kou              | Dr                | IJClab/IN2P3   | Takashi Kaneko     | Assoc.Prof         | KEK      |
|                                    |         |  | Aurélien Martens     | Dr                | IJClab/IN2P3   | Shunsuke Kurokawa  | Mr                 | TMU      |
|                                    |         |  | Roman Mizuk          | Dr                | IJClab/IN2P3   | Taichiro Koga      | Assist. Prof       | KEK      |
|                                    |         |  | Zhiqing Zhang        | Dr                | IJClab/IN2P3   | Yuxin Liu          | Mr                 | Sokendai |
|                                    |         |  | Farah Mawas          | Ms                | IJClab/IN2P3   | Yu Nakazawa        | Assist Prof.       | KEK      |
|                                    |         |  | Flavien Callet       | Mr                | IJClab/IN2P3   | Shohei Nishida     | Prof               | KEK      |
|                                    |         |  | Kylian Demory        | Mr                | IJClab/IN2P3   | Kenta Uno          | Assist Prof        | KEK      |
|                                    |         | Francois Le Diberder   | Emeritus             | IJClab/IN2P3      | Yuta Takinami  | Mr                 | Niigata            |          |

# Goal

- Search for new physics exploiting the Belle and Belle II data, following two paths:
  - **Precision measurements** to test the agreement with Standard Model predictions (CP violation, CKM matrix, lepton flavor universality tests)
  - Search for **forbidden decays** (lepton flavor violating decays)



- Belle II analyses still based on Run1 data:
  - 363 fb-1 at Y(4S)
  - 61 fb-1 below/above
- Can be combined with Belle dataset:
  - 711 fb-1 at Y(4S)
  - 269 fb-1 below/above

useful for tau analyses!



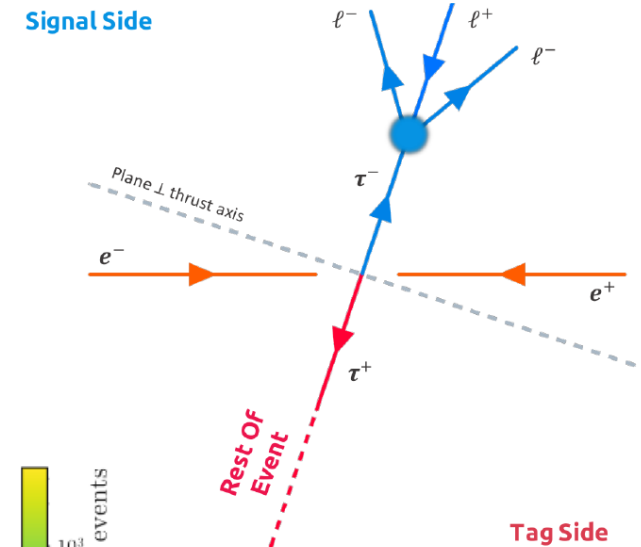
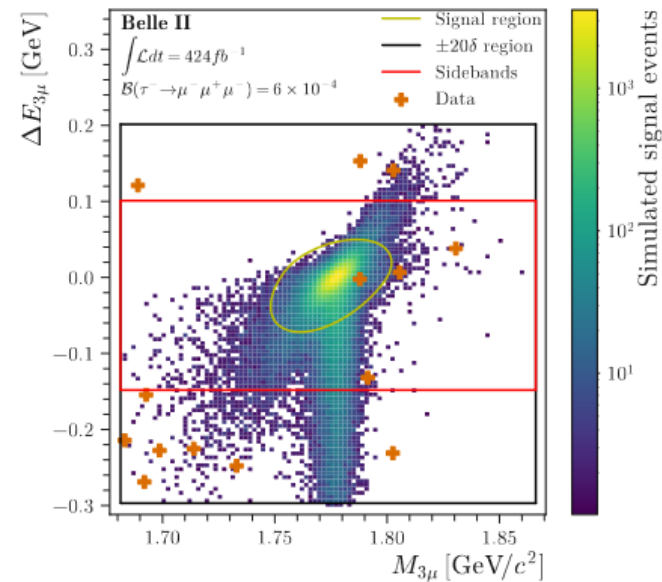
# $\tau$ LFV decays: $\tau \rightarrow 3\mu$

- Golden channel for LFV searches (competition with LHC)
- Traditional  $\tau$  reconstruction at B factory is using a tagging of the non-signal  $\tau$
- We set up a new untagged method, only reconstructing the signal side and using properties of the Rest of Events to lower background
- First application: search for  $\tau \rightarrow 3\mu$

World best limit, using Belle II data only

$\text{BR}(\tau \rightarrow 3\mu) < 1.9 \cdot 10^{-8}$  at 90% CL

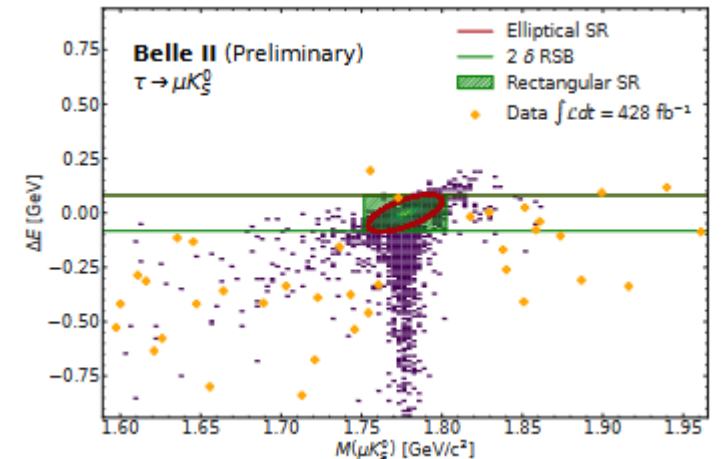
Published in [JHEP09 \(2024\) 06](#)





# $\tau$ LFV decays: $\tau \rightarrow e l l'$ and $\tau \rightarrow l K_s$

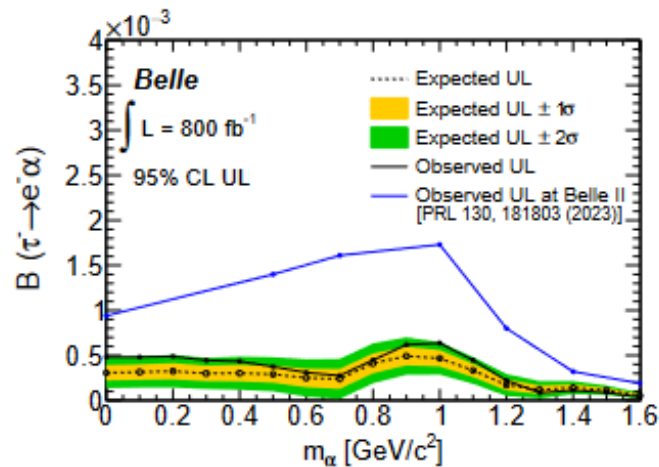
- The untagged method was also applied to  $\tau \rightarrow e l l'$  ( $l=e,\mu$ ) with Belle II data
  - More difficult because of non-simulated low multiplicity background, had to derive a data-driven selection
  - Signal obtained from fit of the reconstructed  $\tau$  mass for the 5 modes
  - Preliminary results shown at winter conferences, should be on arXiv soon
- We also searched for  $\tau \rightarrow l K_s$  with Belle + Belle II data
  - Untagged method less powerful than traditional methods
  - First  $\tau$  analysis combining Belle and Belle II data, best limits!
  - Submitted to JHEP, <https://arxiv.org/abs/2504.15745>



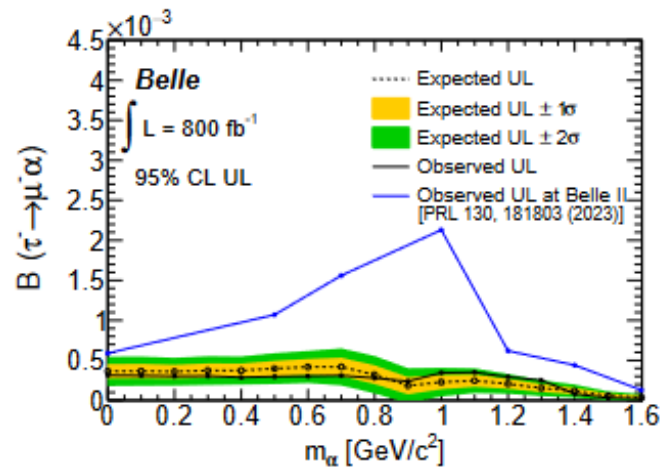


# $\tau$ LFV decays: $\tau \rightarrow l\alpha$

- Search for decays to a lepton + undetected spin-0 particles (axion like), with Belle data
- Mass range  $0 < m_\alpha < 1.6$  GeV
- New method to determine the  $\tau$  direction, will be used in Belle II
- World best limits obtained
- Submitted to JHEP, <https://arxiv.org/pdf/2503.22195>



(a)  $\tau^- \rightarrow e^- \alpha$

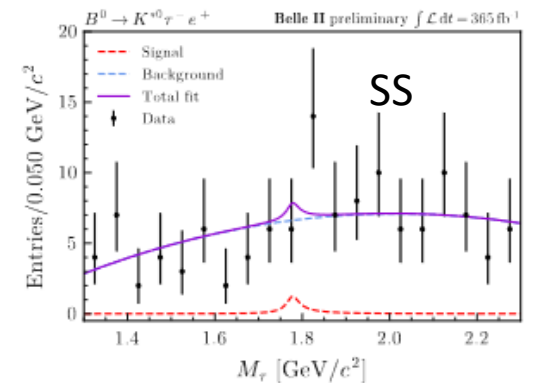
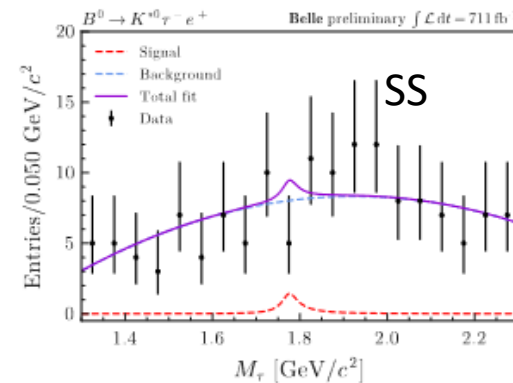
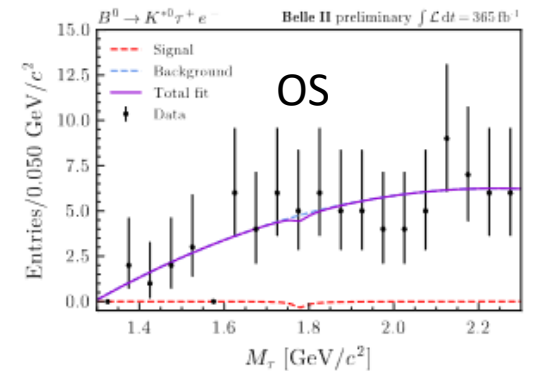
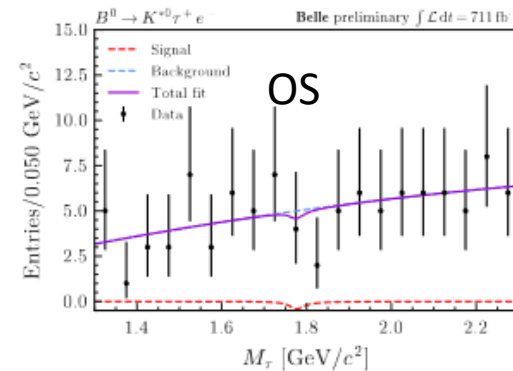
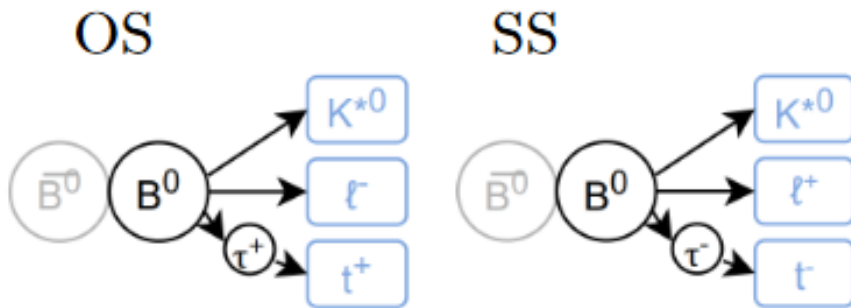


(b)  $\tau^- \rightarrow \mu^- \alpha$



# B lepton flavor violating decays

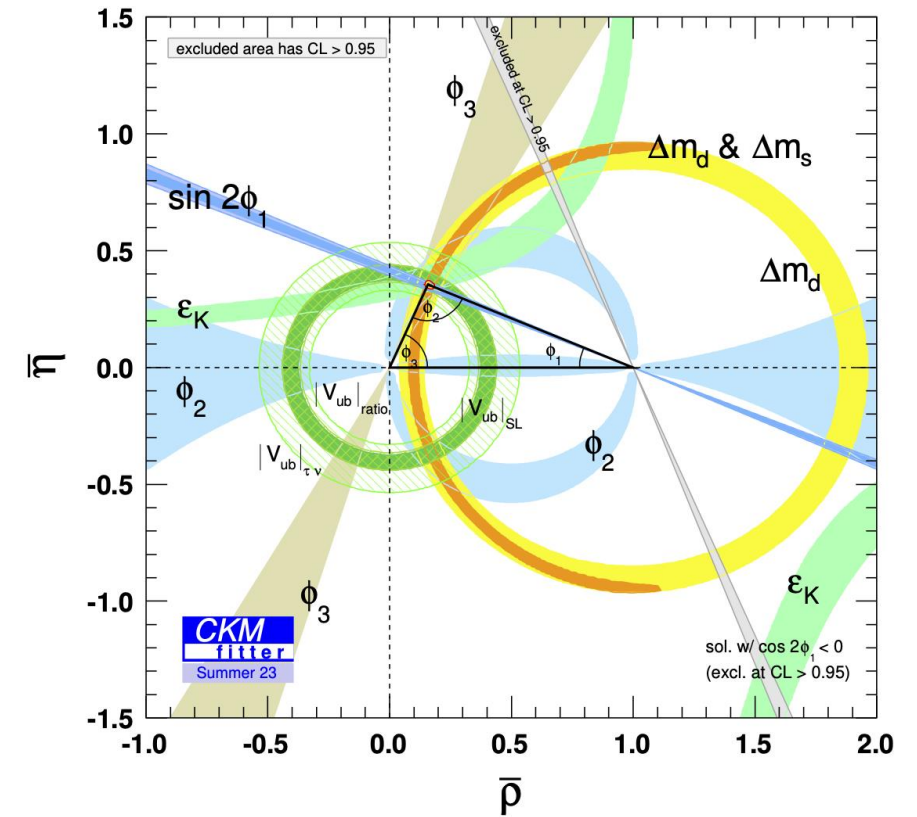
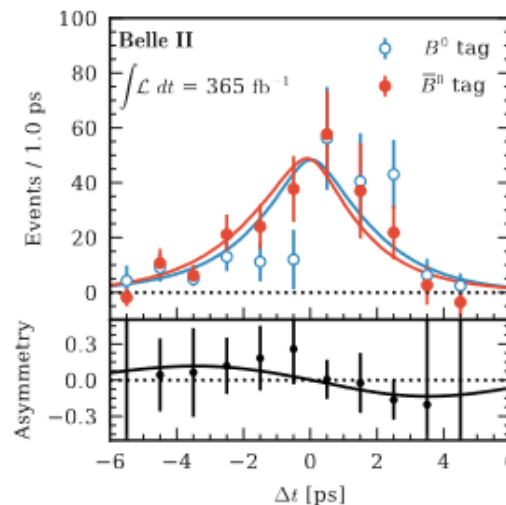
- Search for  $B \rightarrow K^* \tau \ell$  with Belle + Belle II data
  - Use hadronic tagging with Full event interpretation
  - $\tau$  mass reconstructed from rest of event and tagged
  - 4 final states: same/opposite sign,  $e/\mu$
  - First search at a B factory
  - Submitted to JHEP, <https://arxiv.org/pdf/2505.08418>





# CP violation in B decays : $B^0 \rightarrow \rho^+\rho^-$

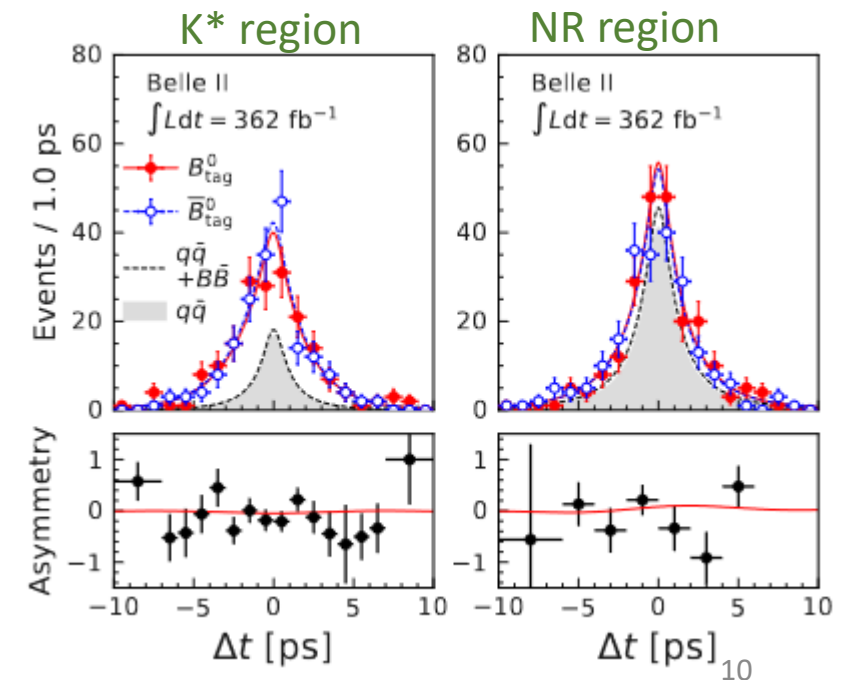
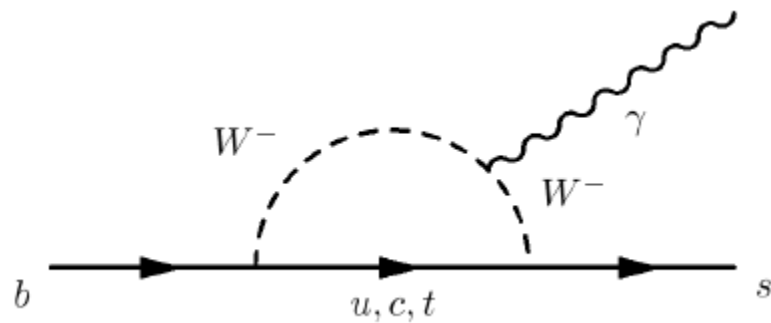
- Precision measurement of unitarity triangle allows to test the presence of new physics
- $\phi_2$  is the least well known angle, can be measured using  $B^0 \rightarrow \rho^+\rho^-$  decay
- Belle II data are used to measure the branching fraction, longitudinal polarization and CP violation parameters
- Precision better than Babar with less statistics
- Published in [PRD](#)





# CP violation in B decays : $B^0 \rightarrow K_s \pi^0 \gamma$

- In SM, the  $\gamma$  are predominantly left-handed
- Can be different in case of BSM contribution, leading to mixing-induced CP violation
- Measure time-dependent CP asymmetries with Belle II
- Results consistent with SM, improved precision compare to Belle and Babar ( $K_s$  reconstruction, SVD acceptance)
- Published in PRL, [Phys. Rev. Lett. 134, 011802 \(2024\)](#)





# Hadronic B decays

- Branching fraction measurements of  $B \rightarrow D(*)KK(*)$  and  $B \rightarrow DDs$  with Belle II data
  - Only 40% of total B width is known, the unmeasured decays are simulated with Pythia fragmentation model
  - **Improving the simulation is crucial for better B tagging efficiency**
- Improve measurement on 12 decays (first observation for 3 channels)
- Also performed a mass and helicity analysis for  $B \rightarrow DKK$  channels
- Published in [JHEP08\(2024\)206](#)

$$\begin{aligned} \mathcal{B}(B^- \rightarrow D^0 K^- K_S^0) &= (1.82 \pm 0.16 \pm 0.08) \times 10^{-4}, \\ \mathcal{B}(\bar{B}^0 \rightarrow D^+ K^- K_S^0) &= (0.82 \pm 0.12 \pm 0.05) \times 10^{-4}, \\ \mathcal{B}(B^- \rightarrow D^{*0} K^- K_S^0) &= (1.47 \pm 0.27 \pm 0.10) \times 10^{-4}, \\ \mathcal{B}(\bar{B}^0 \rightarrow D^{*+} K^- K_S^0) &= (0.91 \pm 0.19 \pm 0.05) \times 10^{-4}, \\ \mathcal{B}(B^- \rightarrow D^0 K^- K^{*0}) &= (7.19 \pm 0.45 \pm 0.33) \times 10^{-4}, \\ \mathcal{B}(\bar{B}^0 \rightarrow D^+ K^- K^{*0}) &= (7.56 \pm 0.45 \pm 0.38) \times 10^{-4}, \\ \mathcal{B}(B^- \rightarrow D^{*0} K^- K^{*0}) &= (11.93 \pm 1.14 \pm 0.93) \times 10^{-4}, \\ \mathcal{B}(\bar{B}^0 \rightarrow D^{*+} K^- K^{*0}) &= (13.12 \pm 1.21 \pm 0.71) \times 10^{-4} \end{aligned}$$

# Other ongoing studies

- Lepton flavor violating decays:



- Search for  $\tau \rightarrow \mu\gamma$  and  $B \rightarrow \rho\tau e / \rho\tau\mu$

- Lepton flavor universality tests and related measurements



- Measurement of  $R(D^*)$
- Measurement of  $BR(B \rightarrow \tau\nu)$  with semileptonic tagging
- Search for  $B \rightarrow \tau\tau$  with hadronic tagging

- Others:



- $\tau$  decays with polarized e- beam
- Phenomenological analyses of B semileptonic decays
- Time dependent CP violation in  $B \rightarrow K_s K_s$



- Hadronic  $\tau$  decays
- BF and CP violation in  $b \rightarrow s\gamma$

# Summary and conclusion

- Achievements:
  - 4 publications :  $\tau \rightarrow 3\mu$  ,  $B^0 \rightarrow \rho^+\rho^-$  ,  $B^0 \rightarrow K_s\pi^0\gamma$  ,  $B \rightarrow D(^*)KK(^*)$
  - 3 submitted
- Collaborations:
  - Visit of **Tejhas Kapoor** at KEK
  - Visit of **Akimasa Ishikawa** at CPPM
  - **S. Hashimoto** organized Belle II physics week with other Belle II colleagues
  - + online meetings
- Plan for next fiscal year:
  - Finalize ongoing studies on  $\tau \rightarrow \mu\gamma$  ,  $B \rightarrow \rho\tau e / \rho\tau\mu$  ,  $BR(B \rightarrow \tau\nu)$  and others
  - Develop a phenomenological collaboration regarding the impact of the different LFV channels and of their correlations with LFU