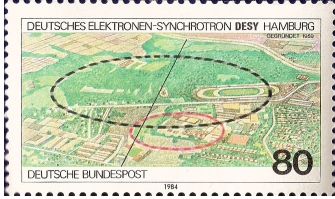


Status of Belle II

PRC, 12 November 2025

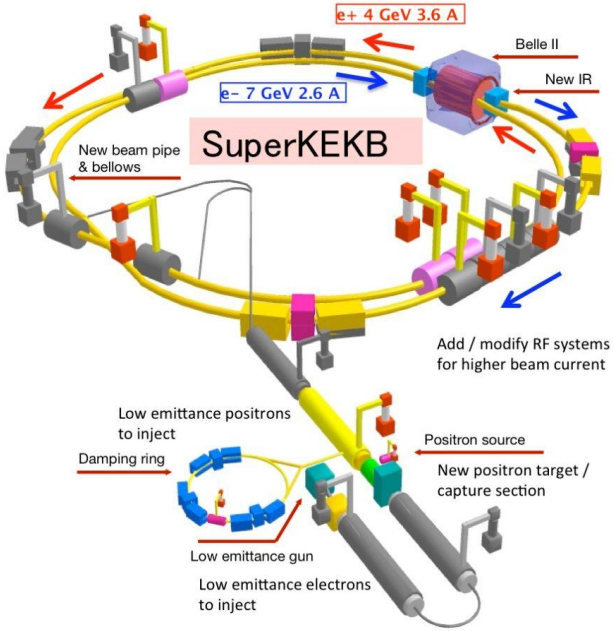
Sasha Glazov on Behalf of DESY Belle II group

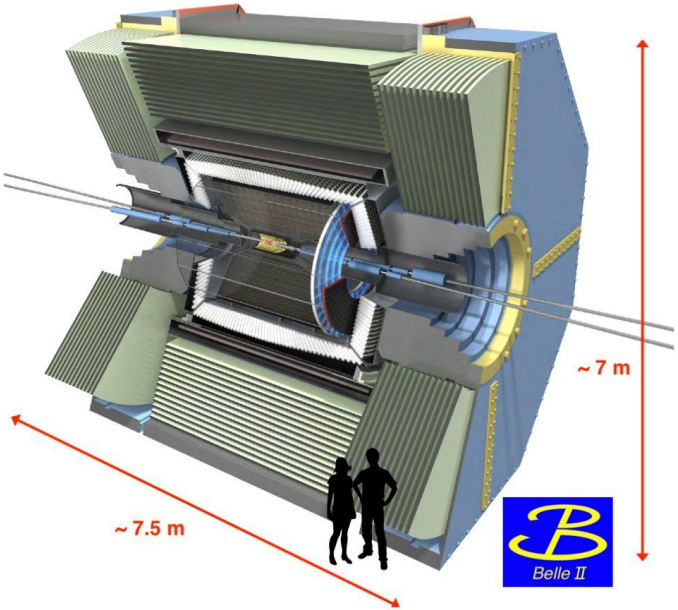
Belle II and SuperKEKB

Collected in total:	575 fb^{-1}

SuperKEKB:

- e^+e^- collider with energies 4 GeV and 7 GeV operating around *Y(4S)* resonance
- Achieved world-record peak luminosity of **5.1 x 10^{34} cm^{-2} s^{-1}**





Belle II:

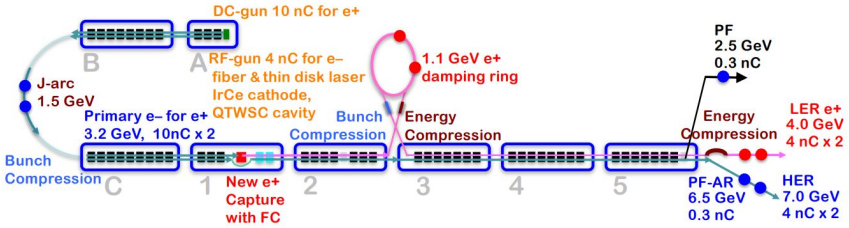
- Nearly 4π detector
- Tracking, PID, and photon reconstruction capabilities
- Well-suited to measure decays with missing energy, photons in the final state, and inclusive measurements

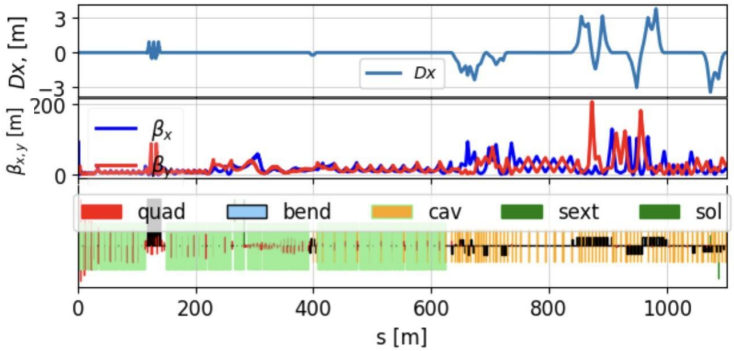
DESY and Belle II

DESY group contributes to all aspects of Belle II operation: from help with accelerator to several key physics measurements

- SuperKEKB operation
  - Injection studies (A. Polo, I. Agapov)
  - Studies of beam losses (N. Sharafi, A. Eichler, S. Hallerberg)
- Detector operation
  - PXD, drift chamber
- Collaborative services
  - domain, gitlab, wiki
- Computing
  - NAF, grid
- Software
  - PXD, drift chamber, tracking software development, alignment
- Performance
  - Group coordination (SG)
  - Neutral group convenership, studies (D. Pitzl, S. Raiz)
  - Tracking, drift chamber studies
- Physics
  - Tau: lepton-flavor universality (m_τ τ_τ, and BR) and V_{us}
  - Semileptonic decays and V_{ub}
  - Flavor-changing neutral currents including $B \to K \nu\nu$ decays
  - Time-dependent CP violation and CKM angles β and α

SuperKEKB injection performance studies





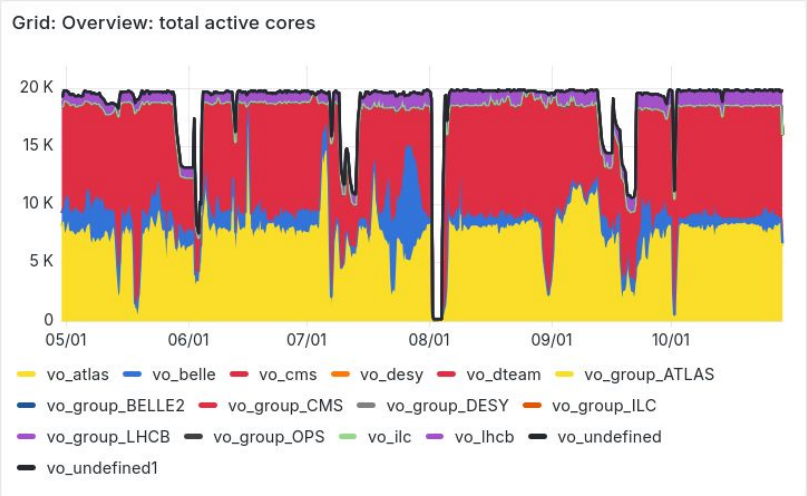
Linac and beam transport for electrons linear optical functions (OCELOT)

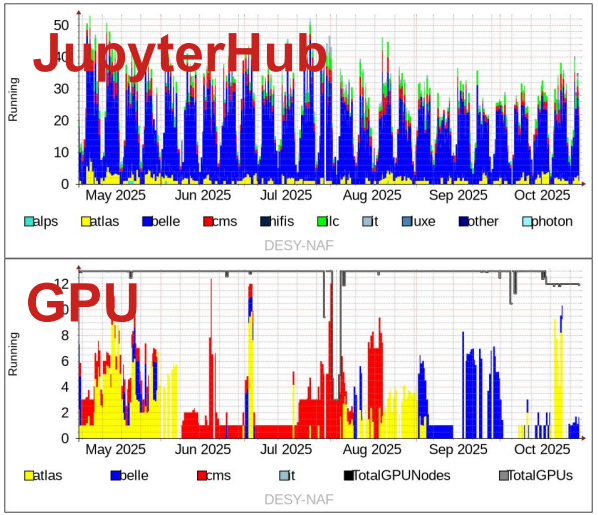
PhD thesis project:
Andrea Aguirre Polo,
March 2025 – Feb 2028
Supervisor Ilya Agapov (DESY)
KEK supervisors: Takashi Mori, Naoko Iida

- **Injection inefficiency** due to not fully understood emittance growth is one of the limiting factors for SuperKEKB luminosity
- DESY has excellent expertise in operating modern high-energy XFEL linac and developing beam transport simulation framework OCELOT
- Goal: identify problems and improve injection performance

Belle II computing: Grid and NAF

- The DESY is a major contributor to Belle II Grid computing
- Analysis Facility (NAF)
  - NAF at DESY is open (on request) to all Belle II users
  - Belle II users: **315** registered user (119 DE inst.)
  - Computing: batch (BIRD), GPU, JupyterHub
  - Project storage: DUST (272TB)
  - Mass storage: dCache (1132TB)(BELLE-LOCAL-SE)
  - NAF storage now official part of Belle II computing (RUCIO, FTS)





Preparations for 2025c-2026ab run

- **2025c-2026ab run:**
  - 7 month run
  - Started Nov **5th**, short winter holiday break
  - Continue until end of May

- **Main goals of the run:**
  - Double Belle II data set (575 fb^{-1} → **$1ab^{-1}$**)
  - Achieve **$1 \times 10^{35}\ cm^{-2}\ s^{-1}$** instantaneous luminosity
  - Stable and safe SuperKEKB operation

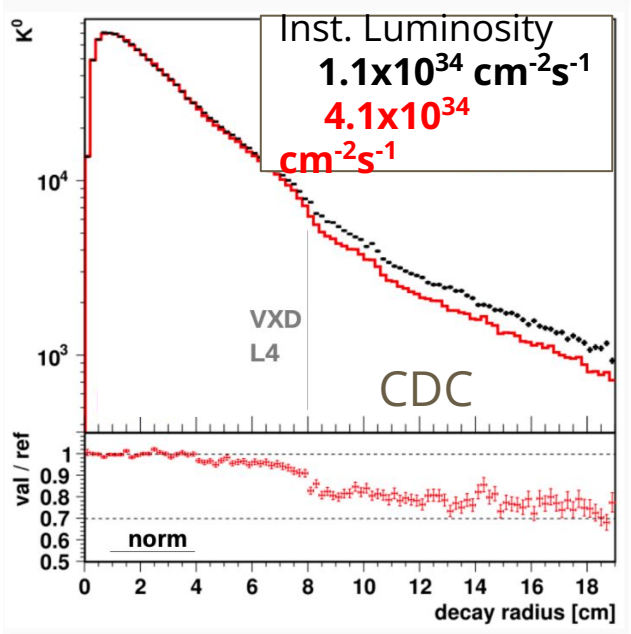
PXD preparation for the data taking

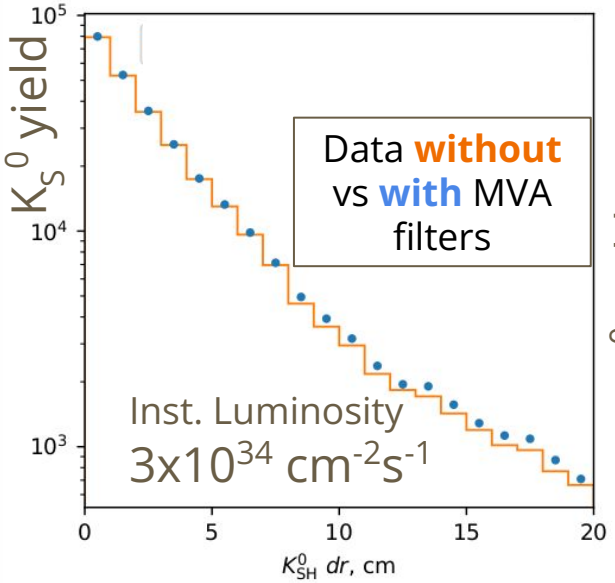
DESY fellow, Luisa, in front of the new DAQ system at KEK

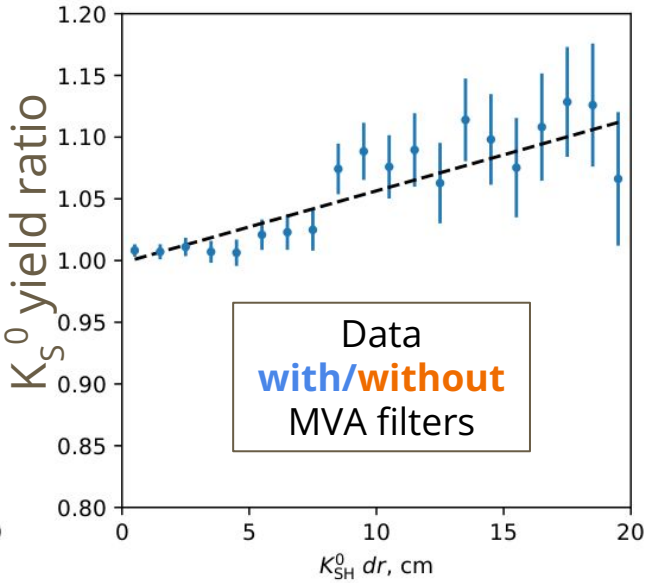
- Improving PXD safety:
  - Development of **fast PXD emergency shutdown** to minimise damages from beam losses (Bonn)
  - Studies of possible early PXD emergency shutdown signals
- Re-commissioning after DAQ upgrade during shutdown:
  - PXD successfully participated in cosmic runs before beam operation

PXD remains off until stable operation of SuperKEKB is achieved

Tracking for data taking: improvements for K_S^0





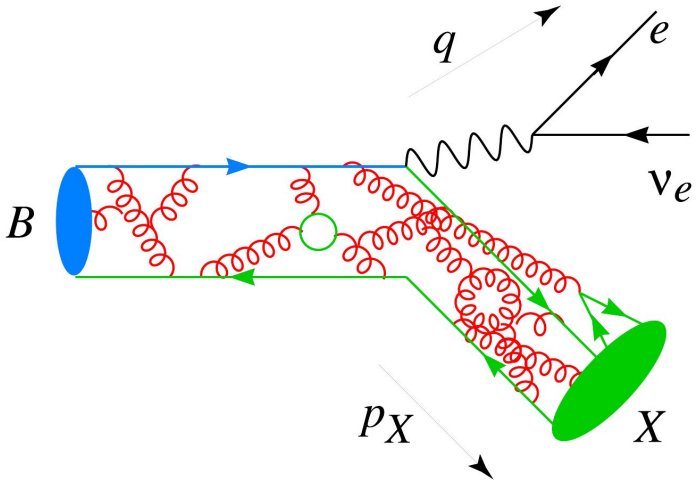


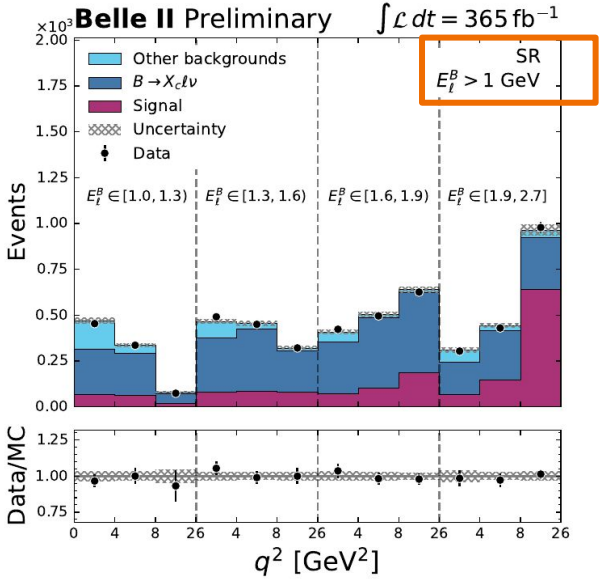
Higher background has significant impact on K_S^0 reconstruction in Belle II drift chamber (CDC).

Improvements for the upcoming data taking: dedicated MVA filter which removes background hits reduces the losses by up to **10%** in the drift chamber volume.

Physics results since last PRC

Measurement of $|V_{ub}|$ in inclusive B meson decays





→Signal composition fit to data differential in E^B_l and q^2

- Inclusive $B \to X_u l\nu$ decays: consider any $b \to u l\nu$ decay
- Second B meson reconstructed fully hadronically to suppress backgrounds and define X_u
  - $B \to X_u l\nu$: $B \to X_c l\nu$ about 1 : 50
  - **Challenge**: suppress X_c background by keeping inclusivity
- Measurement of partial BF in **three phase space regions** defined by lepton energy E_l^B, q^2, and hadronic mass M_X

Measurement of $|V_{ub}|$ in inclusive B meson decays

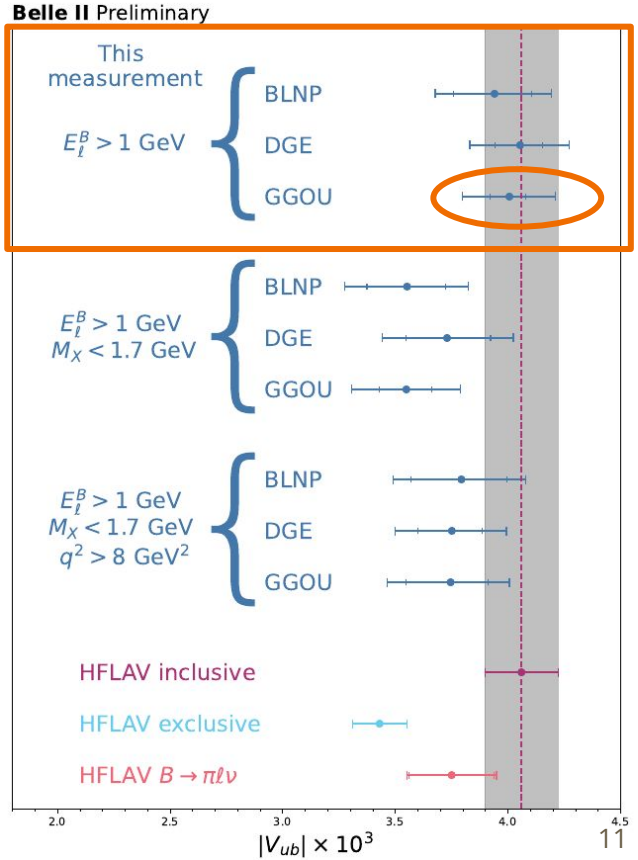
$$|V_{ub}| = (4.01 \pm 0.11(\text{stat}) \pm 0.16(\text{syst})^{+0.07}_{-0.08}(\text{theo})) \times 10^{-3}$$

using $E_l^B > 1$ GeV and GGOU predictions

- Largest systematic uncertainties related to signal and ***B→X$_c$lν*** background modeling
- **Precision better than Belle measurement on 711 fb^{-1}** thanks improved hadronic tag, better soft ***π*** reconstruction, and stronger suppression of backgrounds

Result presented at EPSHEP 2025, paper to be submitted soon

Consistent with HFLAV inclusive average



Future plans

Belle II and Helmholtz strategic plans

Helmholtz ***Matter***

MATTER AND THE UNIVERSE **MU**

Topic **MU-FPF**
Fundamental Particles and Forces

Fundamental Interactions
Pushing the limits of our under-standing of fundamental interactions

- EW precision and Higgs physics (HH, H potential)
- SF QED
- QCD (incl. lattice and QC)
- Probing SM extensions

The Origin of Mass
Covering the puzzle of the origin of mass and of flavour, and the imbalance between matter and ant-matter in the universe

- EWSB
- Higgs portal
- Top, beauty, tau physics
- CPV
- LFU

The Early Universe
Exploring the evolution of the early universe and the nature of the dark sector

- Cosmology (inflation, …)
- DM searches (WIMPs, axions, ALPs, …)
- GW
- EW phase transitions

MATTER AND TECHNOLOGIES **MT**

- SRF systems
- Hadron & electron acc.
- Beam control, diagnostics, dynamics
- Plasma accelerators

Accelerator R&D (ARD)
Accelerator Science and Technology for highest performance and sustainability

- Sensing and detecting
- Quantum technologies
- Systems and systems technologies
- Detection methods

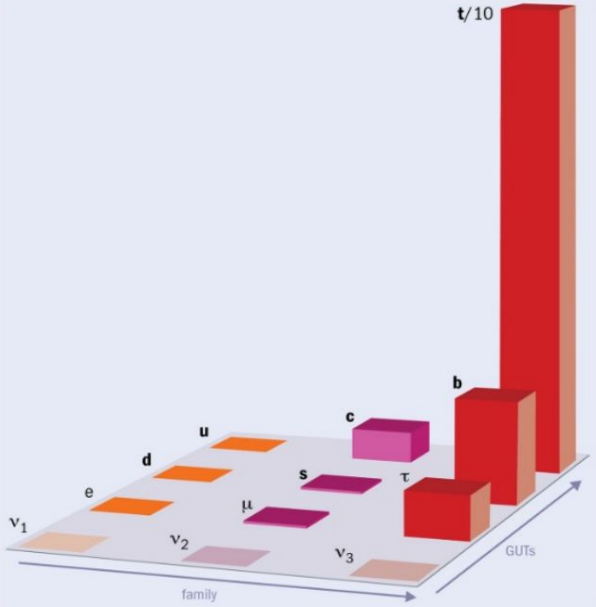
Detector Technologies and Systems (DTS)
Advancing discovery through world-leading detector innovation

- Frontier methods in computational and data science
- Sustainable solutions
- Innovation for research infrastructures

Data Management and Analysis (DMA)
Enabling and accelerating MATTER science with frontier digital solutions

Flavor puzzle

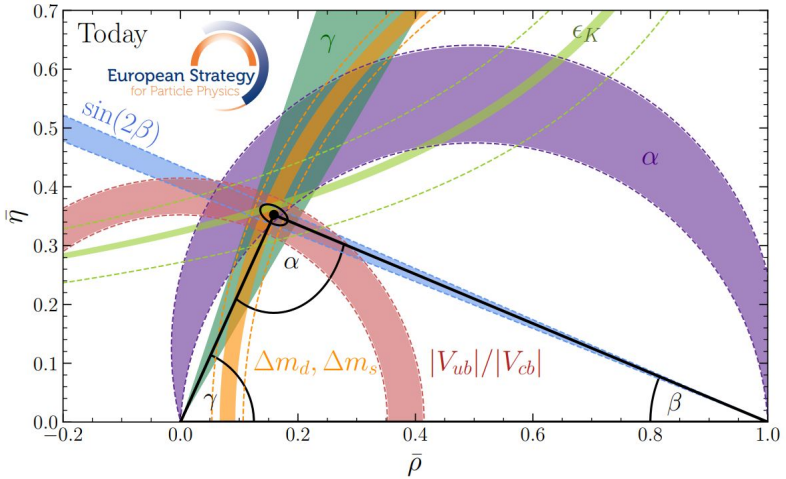
$$U_{\mathrm{PMNS}} \sim \begin{pmatrix} 0.8 & 0.5 & 0.15 \\ 0.4 & 0.6 & 0.7 \\ 0.4 & 0.6 & 0.7 \end{pmatrix} \quad \nu \longleftrightarrow q \quad V_{\mathrm{CKM}} \sim \begin{pmatrix} 0.97 & 0.22 & 0.004 \\ 0.22 & 0.97 & 0.04 \\ 0.009 & 0.04 & 1.0 \end{pmatrix}$$



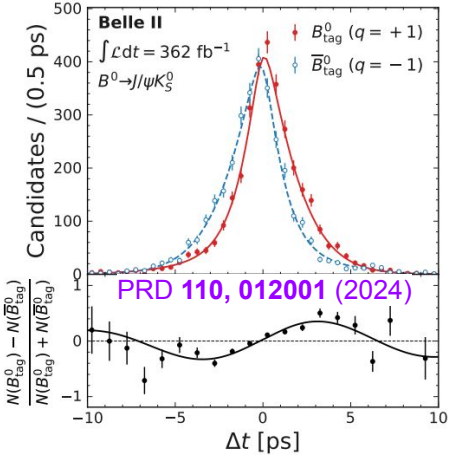
- Why do we have 3 fermion families?
- Why is quark mixing strongly hierarchical, while neutrino mixing is large and nearly democratic?”
- Could the observed patterns reflect New Physics, preferentially affecting the **3rd generation** and, via mixing, the **2nd**?

→Probe NP with **precision measurements** of CKM matrix, lepton universality, and studies of **rare** flavor-changing neutral-current **decays**

B-physics unitarity triangle



$\beta = 23.2 \pm 1.61^{\circ}$



PRD **110, 012001** (2024)

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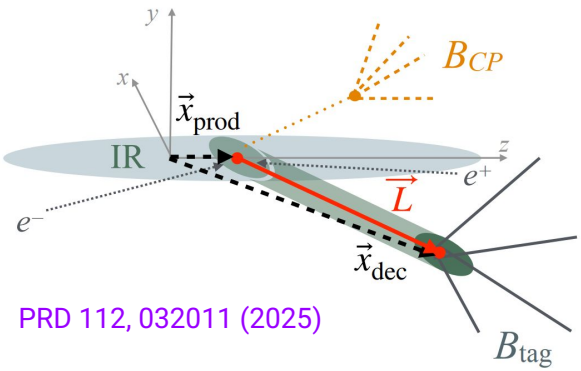

PRD 112, 032011 (2025)

- Overconstrained measurements of the unitarity triangle checks CKM paradigm
- Measurement of the angle ***β*** using GNN-based **signal-side** flavor tagger
- Future measurements of the angle ***α***:
  - including ***B*** decays **without decay time** information such as $B^0 \to \pi^0\pi^0$
  - using **tag-side** decay time, possible with **PXD** and **nano-beams** of SuperKEKB

CKM first row unitarity and V_{us}

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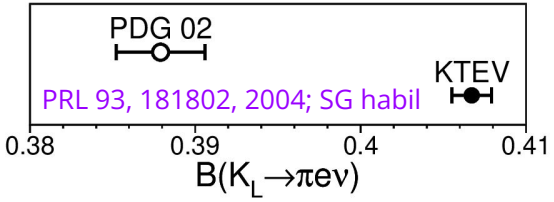

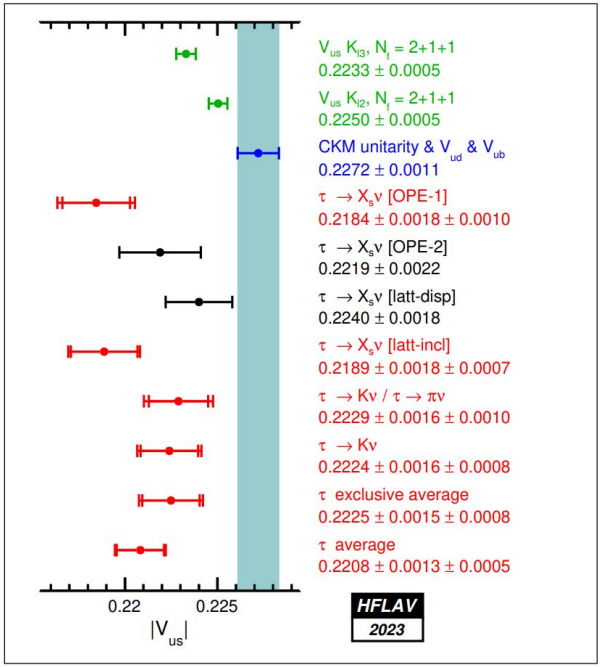

- Unitarity of the CKM matrix is probed with highest precision for the first row: $|V_{ud}|^2+|V_{us}|^2+|V_{ub}|^2=1$
- $|V_{us}|$ is most precisely measured using semileptonic kaon decays and ratio of leptonic kaon and pion decays
- A long ~40 years history of **tensions** initially due to biased PDG average recently reappearing due to updated lattice QCD calculations and improved radiative corrections
- **Tau decays** involving net strangeness in the final state provide alternative determination with different theory uncertainties
- **Belle II is well suited for the experimental update**

Lepton flavor universality

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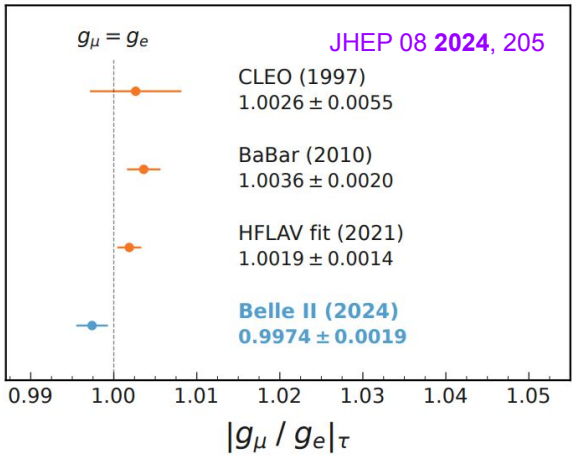
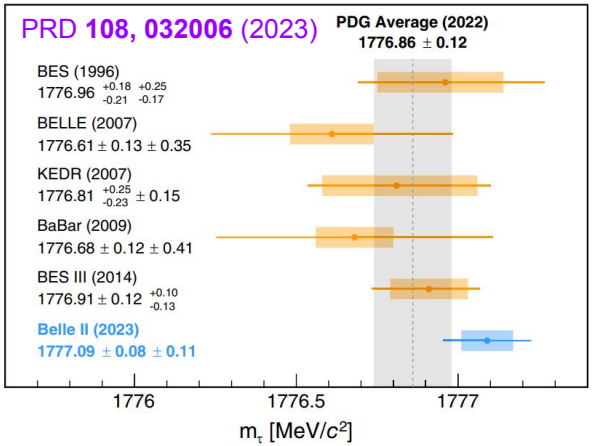
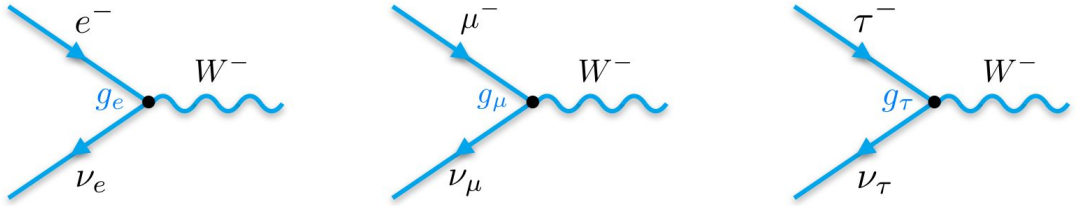






- Identical couplings between W and leptons (LFU)
- Several probes of LFU using **leptonic decay widths:**
  - $\tau \to \mu\nu\nu$ vs $\tau \to e\nu\nu$
  - $\tau \to e\nu\nu$ vs $\mu \to e\nu\nu$

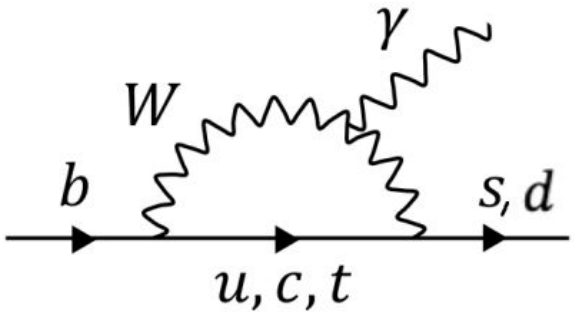
should be the same, accounting for **mass differences**

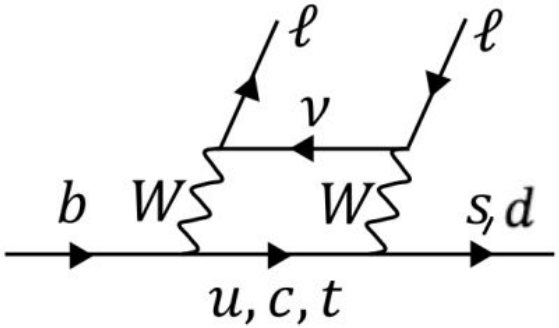
  - Ratio of coupling constants g_τ over g_μ can be probed by comparing **widths** of two-body hadronic decays, $\tau \to h\nu$ vs $h \to \mu\nu$, where h is K or π

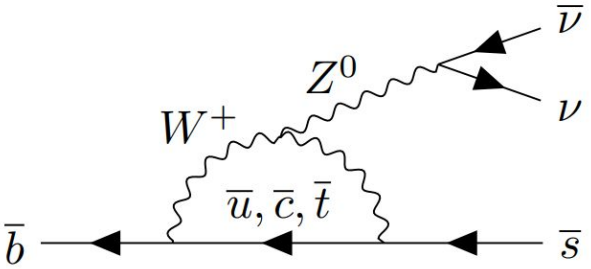
- **Belle II can measure all ingredients**: **τ mass**, **lifetime**, and **branching fractions** in a **single experiment**

Pushing systematics to permile level

Flavor-changing neutral-current $b \to s$ transitions







- Flavor-changing neutral-current $b \to s$ transitions are suppressed in SM, while many BSM theories predict significant contributions
- Several observables have clean theoretical predictions and show tensions between data and SM, cleanest are channels with neutrinos in the final state
- Channels involving **3rd** generation interesting in particular

b → s νν transitions at Belle II

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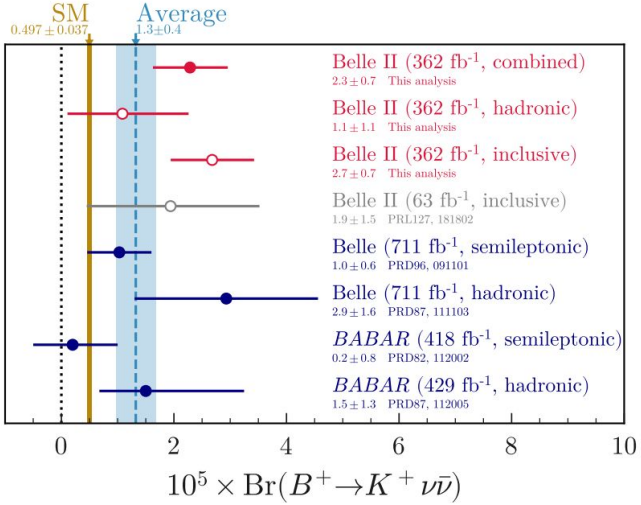
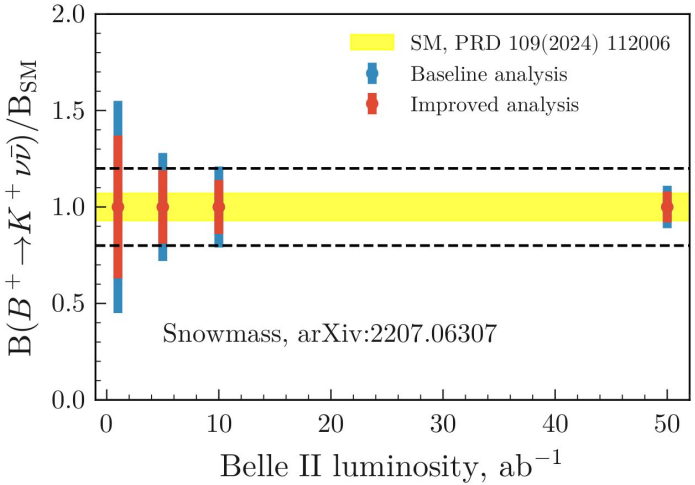




- DESY Belle II group developed **new method** to measure $B^+ \to K^+ \nu\nu$ decays and applied to early data (PRL 127, 181802, 2021)
- **First evidence** for the decay with increased sample (PRD 109, 112006, 2024)
- Extension to other channels: $B^0 \to K_S^0 \nu\nu$, $B^{(+,0)} \to K^{*(+,0)}\nu\nu$
- **Expected observation** with **5 ab^{-1}**, assuming SM branching fraction

Summary

- Belle II has already obtained a number of **important results**, more expected in future as the data samples increase
- DESY is an **essential contributor** to Belle II: from detector operation and preparation for the next run to physics analyses
- DESY group leads the **key measurements** at Belle II in the area of CKM, lepton universality tests and studies of flavor-changing neutral currents.

→These measurements align well with the Helmholtz MU-FPF plans for the next PoF period

Backup

Belle II collaborative services and tools

- DESY hosts crucial collaborative services for Belle II
  - The **domain** belle2.org www.belle2.org
  - The **membership management** system w/ accounts for >1200 active Belle II members
  - **Web services** for documentation and monitoring
  - 35 (virtual) hosts on *XEN* are maintained by DESY and operated by Belle II
- Important changes and developments
  - Enhanced cyber **security** (multi-factor auth, **eduVPN**, intranet)
  - **XWIKI** (finally) succeeded ATLASSIAN's *confluence (in intranet)*
  - A world-wide-open public XWIKI instance is under development
  - newly developed publication database (**pubDB**) succeeded Invenio

Test of lepton flavour universality in τ decays

τ mass, lifetime, BR

The coupling of leptons to W bosons is flavour-independent

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

$\mu - e$ universality

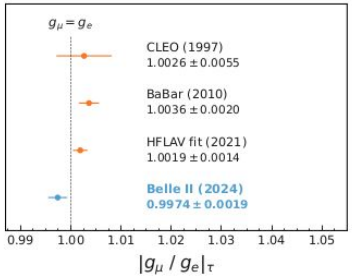
- Most precise test from π decays
- Followed by τ decays
  - Belle II has the most precise single measurement in τ decays

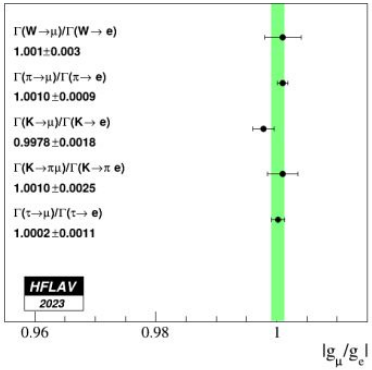
$\tau - e$ universality

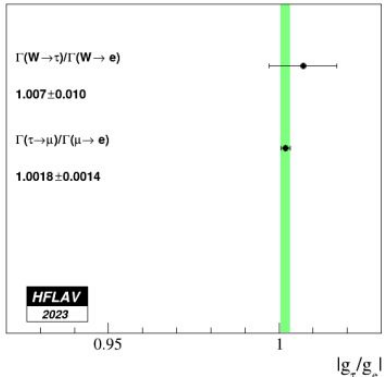
- An order of magnitude more precise measurements from τ decays (BaBar) than from W decays

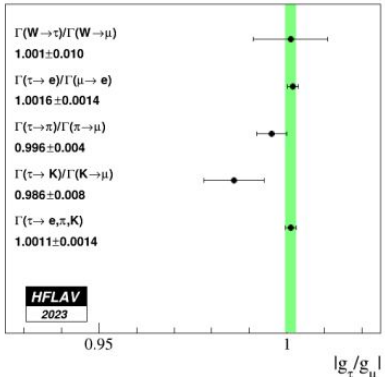
$\tau - \mu$ universality

- τ/μ decays have the best precision









Belle II prospects:

- Require measurements of absolute branching fractions: $\tau \to e, \mu, \pi, K$
- Initial studies show promising results for hadronic and leptonic branching fraction measurements