Flavor Physics with Belle and Belle II

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Flavor Physics

Needs for new physics beyond the Standard Model of particle physics
- What made the matter-antimatter asymmetry of the Universe?
- What is dark matter? - What gave masses to the neutrinos?
- What makes the Higgs boson so light? ...

Approach to the NP of flavor physics
- Study particle behaviors associated with the quark and/or lepton flavor change, and compare the measured parameters with the SM prediction → discrepancy = discovery of the NP.
- Measure as many physics observables as possible, develop a collection of discrepancies in the observables (right table), and infer the true model of the new physics from the collection.

"DNA" of flavor physics effects
★★★ large effects, ★★ visible but small

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<th>AC</th>
<th>RVV2</th>
<th>AM</th>
<th>JLL</th>
<th>FBM3SM</th>
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Belle II Experiment

In the quest for the new physics, we started an $e^+ - e^-$ collider experiment Belle II in Japan in March 2019.

- **SuperKEKB accelerator**
  - $7 \text{ GeV} e^- + 4 \text{ GeV} e^+ \rightarrow b\bar{b}, \tau^+\tau^-, c\bar{c}$
  - KEK Taubuca, KEKB Main Ring, Lineac, Damping Ring

- **Belle-II detector**
  - $e^-$, $e^+$
  - W: 7.7m, D: 7.2 m, H: 7.9 m

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<tr>
<th>$\int \mathcal{L} dt$</th>
<th>Current record</th>
<th>Target / design</th>
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<tr>
<td>$\mathcal{L}_{\text{peak}} [\text{cm}^{-2}\text{s}^{-1}]$</td>
<td>$424 \text{ fb}^{-1}$</td>
<td>$50 \text{ ab}^{-1}$</td>
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<td>$4.7 \times 10^{34}$ (WR)</td>
<td>$60 \times 10^{34}$</td>
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- **Silicon detectors** for particle position measurement
- **Drift chamber** for $p_t$ and $dE/dx$ measurement
- **TOP counters** and **ARICH counters** for PID
- **CsI(Tl) crystals** for $e^\pm$ and $\gamma$ calorimetry
- **Iron/RPC sandwiches** for $K_L$ and $\mu$ detection

**Introduction**
Test of the CKM Unitarity

CKM triangle
- The 9 elements of the quark mixing matrix a.k.a CKM matrix form a triangle, CKM triangle, for their unitarity condition.

- The CKM unitarity is tested by measuring the interior angles and sides of the CKM triangle.

CKM unitarity and new physics
- The new-physics particle propagated in the box diagram of the $B^0 - \bar{B}^0$ mixing may violate the CKM-matrix unitarity.

- By precisely testing the CKM unitarity, Belle II can search for the new physics in an energy scale of up to ~200 TeV (when the new physics does not have a generation hierarchy).

Motivation for the CKM unitarity test at Belle II
CKM Triangle Angle $\phi_1$

- The CP asymmetry of the proper time difference distribution $\Delta t$ of the two $B$ mesons:

$$\mathcal{A}(\Delta t) \equiv \frac{\mathcal{P}_{B^0}(\Delta t) - \mathcal{P}_{B^0}(\Delta t)}{\mathcal{P}_{B^0}(\Delta t) + \mathcal{P}_{B^0}(\Delta t)}$$

$\mathcal{A}(\Delta t)$ for $B^0 \to J/\psi K^0_S$ ($b \to c\bar{c}s$)

- $\mathcal{A}(\Delta t) = S_{J/\psi K^0_S} \sin(\Delta m_d \Delta t) + A_{J/\psi K^0_S} \cos(\Delta m_d \Delta t)$

- $S_{J/\psi K^0_S} \approx \sin 2\phi_1$

$S_{J/\psi K^0_S}$ and $A_{J/\psi K^0_S}$ results

- $S_{J/\psi K^0_S} = 0.720 \pm 0.062 \pm 0.016$ (stat) (syst)
- $A_{J/\psi K^0_S} = 0.094 \pm 0.044^{+0.04}_{-0.017}$

- $\sigma_{syst}^{Belle II} < \sigma_{syst}^{Belle}$ for Belle 140 fb$^{-1}$ ($c\bar{c})K^0$ analysis thanks to improved $\Delta t$ resolution.
**Effective $\phi_1$ for $b \to sq\bar{q}$**

- $A(\Delta t) = S_{sq\bar{q}} \sin(\Delta m_d \Delta t) + A_{sq\bar{q}} \cos(\Delta m_d \Delta t)$
- $S_{sq\bar{q}} \approx -\eta_{CP} S_{J/\psi K_S^0}$ in the SM since no $CP$-violating phase in the least-order $b \to sq\bar{q}$ diagram; $S_{sq\bar{q}} \neq -\eta_{CP} S_{J/\psi K_S^0}$ may happen if a NP particle propagated in the $b \to sq\bar{q}$ loop affects the decay.

**$S_{sq\bar{q}}$ and $A_{sq\bar{q}}$ results for $\phi K_S^0$ ($\eta_{CP} = -1$) and $K_S^0 K_S^0 K_S^0$ ($\eta_{CP} = +1$)**

- On par with the most precise result for $A_{\phi K_S^0}$.
- Improvement on $S$ by 10-20% for the same signal yield w.r.t. Belle/BaBar.

- Challenge: no prompt tracks from $B$ decay → uniquely possible at Belle II.

**New for 2023**

Belle II 362 fb$^{-1}$
Toward CKM Triangle Angle $\phi_2$

- $A(\Delta t) = S_{\pi\pi} \sin(\Delta m_d \Delta t) + A_{\pi\pi} \cos(\Delta m_d \Delta t)$
- $B \to \pi\pi$ is mediated by $b \to u\bar{u}d$ and $du\bar{u}$.
- $S_{\pi\pi}$ and $A_{\pi\pi}$ are related to $\phi_2$ with $S_{\pi\pi} = -\eta_{CP}\sqrt{1 - A_{\pi\pi}^2} \sin(2\phi_2 + 2\Delta \phi_2)$.

$\mathcal{B}r$ and $A_{\pi\pi}$ results

\[ \mathcal{B}r(B^+ \to \pi^+\pi^0) = (5.02 \pm 0.28 \pm 0.32) \times 10^{-6} \]
\[ A_{\pi^+\pi^0} = -0.08 \pm 0.05 \pm 0.01 \]

\[ \mathcal{B}r(B^0 \to \pi^+\pi^-) = (5.83 \pm 0.22 \pm 0.17) \times 10^{-6} \]
**CKM Triangle Angle $\phi_3$**

- $\phi_3$ can be measured through the interference between the $b \to c$ and $b \to u$ transitions.
- The absence of the loop contribution allows extremely clean theoretical prediction of $\phi_3 \to$ good probe of the NP.

$B^\pm \to D_{CP\pm}K^\pm$ results ($D_{CP+} \to K^+K^-, D_{CP-} \to K_S^0\pi^0$)

- $R_{CP\pm} = \frac{\text{Br}(B^- \to D_{CP\pm}K^-) + \text{Br}(B^+ \to D_{CP\pm}K^+)}{\text{Br}(B^- \to D_{\text{flav}}K^-) + \text{Br}(B^+ \to D_{\text{flav}}K^+)}$
  
  $= 1 + r_B^2 + 2r_B \cos \delta_B \cos \phi_3$

- $A_{CP\pm} = \frac{\Gamma(B^- \to D_{CP\pm}K^-) - \Gamma(B^+ \to D_{CP\pm}K^+)}{\Gamma(B^- \to D_{CP\pm}K^-) + \Gamma(B^+ \to D_{CP\pm}K^+)}$
  
  $= \pm 2r_B \sin \delta_B \sin \phi_3 / R_{CP\pm}$

$R_{CP+} = 1.164 \pm 0.081 \pm 0.036 \quad R_{CP-} = 1.151 \pm 0.074 \pm 0.019$

$A_{CP+} = (+12.5 \pm 5.8 \pm 1.4)\% \quad A_{CP-} = (-16.7 \pm 5.7 \pm 0.6)\%$

... best $A_{CP-}$ measurement

$4.7^\circ < \phi_3 < 175.8^\circ, \ 0.069 < r_B < 0.560 \ ... @ 95.4\% \ CL$
CKM Triangle Side $|V_{cb}|$

$B^0 \rightarrow D^{*-} \ell^+ \nu_\ell$ differential cross section

$$\frac{d\Gamma}{d\omega d\cos\theta_\ell d\cos\theta_V d\chi} \propto |V_{cb}|^2 F^2(\omega, \cos\theta_\ell, \cos\theta_V, \chi)$$

Recoil parameter $w \equiv p_B \cdot p_{D^*}/m_B m_{D^*}$

- Split $w, \chi, \cos\theta_V$ distributions into 10 and $\cos\theta_\ell$ into 8 slices.
- Estimate the signal yield from kinematic variable distributions for each slice.

$|V_{cb}|$ result

$\Gamma \sim 10^{-3}$

Belle II Preliminary $\int \mathcal{L} dt = 189.9\text{ fb}^{-1}$

$|V_{cb}|_{\text{BGL}} = (40.9 \pm 0.3 \pm 1.0 \pm 0.6) \times 10^{-3}$ (QCD input)

$|V_{cb}|_{\text{CLN}} = (40.4 \pm 0.3 \pm 1.0 \pm 0.6) \times 10^{-3}$

BGL, CLN ... options for the form-factor bases
B \to X_u \ell^+ \nu_\ell \text{ reconstruction}

- Hadronic tagging with neural networks (efficiency ~ 0.2-0.3%).
- Background suppressed in the hadronic mass $M_X$
- The signal probability is calculated on the momentum transfer $q^2$.

Simultaneous determination of exclusive $|V_{ub}|$ and inclusive $|V_{ub}|$

<table>
<thead>
<tr>
<th>$N_\pi$ variation</th>
<th>Events ($M_X &lt; 1.7$ GeV)</th>
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<tbody>
<tr>
<td>$N_\pi = 0$</td>
<td>MC unc.</td>
</tr>
<tr>
<td>$N_\pi = 1$</td>
<td>Data $B^- \to \pi^+ \ell^- \nu_\ell$</td>
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<tr>
<td>$N_\pi = 2$</td>
<td>$B^0 \to \pi^- \ell^+ \nu_\ell$</td>
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<tr>
<td>$N_\pi \geq 3$</td>
<td>Other $B^- \to X_u \ell^+ \nu_\ell$</td>
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</table>

$B$-$\pi^+ \ell^+ \nu_\ell$ reconstruction

Exclusive: $|V_{ub}|_{\text{excl}} = (3.78 \pm 0.23 \pm 0.16 \pm 0.14) \times 10^{-3}$

Inclusive: $|V_{ub}|_{\text{incl}} = (3.90 \pm 0.20 \pm 0.32 \pm 0.09) \times 10^{-3}$

$|V_{ub}|_{\text{excl}} / |V_{ub}|_{\text{incl}} = 0.97 \pm 0.12$

The weighted average of $|V_{ub}|_{\text{excl}}$ and $|V_{ub}|_{\text{incl}}$ is consistent with the global fit of the CKM triangle within 0.8σ.
Isospin Sum-Rule

Isospin sum-rule: relation among the products of $\mathcal{B}r$ and $\mathcal{A}_{CP}$ for $B \to K\pi$

$$I_{K\pi} = Br(K^+\pi^−)A_{K^+\pi^−} + A_{K^0\pi^+}Br(K^0\pi^+)\frac{\tau_B^0}{\tau_B^+} - 2A_{K^+\pi^0}Br(K^+\pi^0)\frac{\tau_B^0}{\tau_B^+} - 2A_{K^0\pi^0}Br(K^0\pi^0); \quad I_{K\pi}^{SM} = 0$$


**$B^0 \to K^+\pi^-$ results**

**$B^+ \to K_S^0\pi^+$ results**

**$B^+ \to K^+\pi^0$ results**

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<tr>
<th>$\Delta E \equiv E_B^* - \sqrt{s}/2$ [GeV]</th>
<th>$\Delta E \equiv E_B^* - \sqrt{s}/2$ [GeV]</th>
<th>$\Delta E \equiv E_B^* - \sqrt{s}/2$ [GeV]</th>
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<tr>
<td>Cand. / 10 MeV</td>
<td>Cand. / 10 MeV</td>
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$Br = (20.7 \pm 0.4 \pm 0.6) \times 10^{-6}$  
$\mathcal{A}_{CP} = -0.07 \pm 0.02 \pm 0.01$

$Br = (24.4 \pm 0.7 \pm 0.9) \times 10^{-6}$  
$\mathcal{A}_{CP} = -0.05 \pm 0.03 \pm 0.01$

$Br = (14.2 \pm 0.4 \pm 0.9) \times 10^{-6}$  
$\mathcal{A}_{CP} = +0.01 \pm 0.03 \pm 0.01$
Isospin Sum-Rule – Cont’d

$B^0 \rightarrow K_S^0 \pi^0$ time-integrated results
- Challenge: only long lived particle + neutral particle in the signal-side final state → uniquely possible at Belle II.

$Br = (10.2 \pm 0.6 \pm 0.6) \times 10^{-6}$

$\mathcal{A}_{CP} = -0.06 \pm 0.15 \pm 0.05$

$B^0 \rightarrow K_S^0 \pi^0 (\eta_{CP}=-1)$ time-differential results
- $K_S^0 \pi^0$ is a CP eigenstate and the effective $\phi_1$ is defined for $K_S^0 \pi^0 \rightarrow A(\Delta t) = S_{K_S^0 \pi^0} \sin(\Delta m_d \Delta t) + A_{K_S^0 \pi^0} \cos(\Delta m_d \Delta t)$

$S_{K_S^0 \pi^0} = +0.75^{+0.20}_{-0.23} \pm 0.04$ ... consistent with $-\eta_{CP} S_{J/\psi K_S^0}$

$A_{K_S^0 \pi^0} = +0.04 \pm 0.15 \pm 0.05$

TI + TD combination and constraint to $I_{K\pi}$

$Br = (10.5 \pm 0.6 \pm 0.7) \times 10^{-6}$

$\mathcal{A}_{CP} = -0.01 \pm 0.12 \pm 0.05$

$I_{K\pi} = -0.03 \pm 0.13 \pm 0.05$ ... consistent with the SM
Test of the LFU \( (b \to x\ell\nu_\ell) \)

\[
R(X_{e/\mu}) \equiv \frac{Br(B \to Xev_\mu)}{Br(B \to X\mu\nu_e)}
\]

- The \( R(X_{e/\mu}) \) measurement complements the LFU tests made with \( Br(B \to D^{(*)}\tau\nu)/Br(B \to D^{(*)}\ell\nu) \).
  - The inclusive approach reduces the systematic uncertainty.
  - The SM predicts \( R(X_{e/\mu}) = 1 + O(10^{-3}) \).


Signal extraction with \( p_\ell^* \)

Event reconstruction

Reconstruct \( B_{tag} \) with multivariate technique through \( O(10^3) \) modes.

\( X \) (inclusive)

Loose cuts on tracking detector and calorimeter signals.

\( B_{tag}^0/\pm \)

\( Y(4S) \)

\( B_{sig}^0/\pm \)

\( p_\ell^* > 1.3 \text{ GeV/c} \)

\( \nu_\ell \)

\( R(X_{e/\mu}) = 1.0333 \pm 0.010 \pm 0.019 \)

... first inclusive test of \( (e/\mu) \) LFU in \( B \to X\ell\nu_\ell \).
Test of the LFU (angular asymmetries)

Angular asymmetries $A_x$ in $B^0 \to D^{*-} \ell^+ \nu_\ell$

- $A^\ell_x$ values are measured for 3+2 angles $x$ and for $\ell^+=e^+$ and $\ell^+=\mu^+$.
- The SM predicts $\Delta A_x \equiv A^\mu_x - A^e_x = 0$ while the NP may modify $\Delta A_x$ to $\neq 0$.
  - $A^\ell_x$ values are separately measured for zero $D^{*-}$ recoil samples (low $w$) and maximum $D^{*-}$ recoil samples (high $w$).

$\Delta A_x$ results

$A_{FB}$: $dx \to d(\cos \theta_\ell)$

$S_3$: $dx \to d(\cos 2\chi)$

$S_5$: $dx \to d(\cos \chi \cos \theta_V)$

Control channels to confirm no experimental biases in $\Delta A_x$

$S_7$: $dx \to d(\sin \chi \cos \theta_V)$

$S_9$: $dx \to d(\sin 2\chi)$

All $\Delta A_x$ are consistent with zero.
No evidence of the LFU violation with at least the $p$-value of 0.12.
Long-Lived Scalar Particle: \( B \to K(\ast)S \)

- A new (pseudo) scalar particle \( S \) mediating between SM \( \leftrightarrow \) DM only weakly interacts with the SM particles \( \to \) the \( S \) lifetime tends to be long.

- Fully reconstruct a signal \( B \) in \( B^+ \to K^+ S \) and \( B^0 \to K^{\ast 0} (K^+ \pi^-) S \)
  
  with a subsequent \( S \) decay to \( \ell^+ \ell^-, \pi^+ \pi^- \), and \( K^+ K^- \).

- Search for \( S \) with \( 0 \leq c\tau \leq 400 \) cm in \( M_S \) distribution.

No evidence of a new (pseudo) scalar, but the first limits on \( S \) decaying to hadrons.

(Pseudo) scalar mass \( M_S \) [GeV/c^2]
Long Shutdown

- Belle II stopped data taking in summer 2022 for the rise of the electricity rate.

Installation of the pixel detector

- The current pixel detector is only partially instrumented → the installation of the fully instrumented pixel detector is ongoing.

Replacement of PMTs for the PID detector

- MCP-PMTs for the PID detector are replaced before their quantum efficiency gets deteriorated.

Countermeasures to a sudden beam loss

- The frequency of a sudden beam loss was increasing along with the increase of the SuperKEKB currents → may damage accelerator/detector components.
- A new beam-loss monitor and a fast beam-abort system are being developed.

On track to resume the data taking coming winter
Integrated Luminosity Prospects

We aim for achieving $\mathcal{L}_{\text{peak}} = 24 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ by 2026.
Plentiful physics results have been produced by the Belle II (and Belle) data analyses. Several of them are already world leading. Highlights of the new and recent results have been presented today, which include:

- Test of the CKM unitarity,
- Test of the isospin sum-rule,
- Test of the lepton flavor universality, and
- Search for dark-sector particles.
Backup Slides
**B-Meson Lifetime** $\tau_{B^0}$ **and Mixing** $\Delta m_d$

- Test of the machinery readiness for the following CPV measurements based on the $B$-flavor and $\Delta t$ information.

### Event reconstruction

- $B^0 \to D^{*-} (\bar{D}^0 \pi^-) \pi^+, D^- \pi^+$
- $\bar{D}^0 \to K^+ \pi^- n\pi, D^- \to K^+ \pi^- \pi^-$

The $B$ energy is expected to peak at the half of the collision energy.

**$\tau_{B^0}$ and $\Delta m_d$ results**

$\tau_{B^0} = 1.499 \pm 0.03 \pm 0.008 \text{ ps}$

$\Delta m_d = 0.516 \pm 0.008 \pm 0.005 \text{ ps}^{-1}$

... consistent with the WA
CKM Triangle Side $|V_{ub}|$

$B^0 \rightarrow \pi^- \ell^+ \nu_\ell$ reconstruction

- Challenges: large background (low BR) and lack of clean kinematic signatures
- $q\bar{q}$ and combinatorial BG rejection with a BDT.

$|V_{ub}|$ exclusive result: $\frac{d\Gamma(q^2)}{dq^2} \propto |V_{ub}|^2$

- Calculate the recoil momentum $q^2$ by inferring the $\vec{p}_B$ with a modified diamond-frame approach.
- Obtain the differential cross sections in 6 $q^2$ bins.

$|V_{ub}|_{\pi^- \ell^+ \nu_\ell} = (3.55 \pm 0.12 \pm 0.13 \pm 0.17) \times 10^{-3}$

... consistent with the WAs
\[ B \rightarrow D^{(*)} K^- K^0_S \]

- The \( D^{(*)} K K \) sector is mostly unexplored; a few \% \( Br \) is expected while only 0.28\% is measured.
- Better knowledge of this sector is useful to extend the \( b \)-tagging modes.

\begin{align*}
\mathcal{B}(D^+ K^- K^0_S) &= (0.85 \pm 0.11 \pm 0.05) \times 10^{-4} \\
\mathcal{B}(D^{*0} K^- K^0_S) &= (1.57 \pm 0.27 \pm 0.12) \times 10^{-4} \\
\mathcal{B}(D^{*+} K^- K^0_S) &= (0.96 \pm 0.18 \pm 0.06) \times 10^{-4} \\
\mathcal{B}(D^0 K^- K^0_S) &= (1.89 \pm 0.16 \pm 0.10) \times 10^{-4}
\end{align*}

- Some structures are seen in \( m_{KK} \) and Dalitz distributions.
- First \( Br \) measurement for \( D^+, D^{*0}, \) and \( D^{*+} \).
- \( \times 3 \) precision of the last \( Br \) measurement for \( D^0 \) [Phys. Lett. B 542 (2002)].
Search for $\Upsilon(10753)$ in $e^+e^- \to \omega\chi_{bJ}$

- $\Upsilon(10753)$: a resonance-like structure discovered in the energy dependence of cross sections for $e^+e^- \to \Upsilon(nS)\pi^+\pi^-$. 

- $\text{Br}(\Upsilon(10753) \to \omega\chi_{bJ}) \sim \mathcal{O}(10^{-3})$ if the $\Upsilon(10753)$ is a mixing state of conventional bottomonia (3D and 4S).

- $\Upsilon(10753)$ state is searched for in $e^+e^- \to \omega\chi_{bJ}$ at $\sqrt{s} = 10701, 10745, 10805$ GeV.
  - $\omega \to \pi^+\pi^-\pi^0$
  - $\chi_{bJ} \to \gamma\Upsilon(1S); \Upsilon(1S) \to \mu^+\mu^-, e^+e^-$

2D fit on the $M_{\Upsilon(1S)} - M_{\pi^+\pi^-\pi^0}$ distribution → first observation of $e^+e^- \to \omega\chi_{bJ}$ signal

- $\Gamma_{ee}\text{Br}(e^+e^- \to \omega\chi_{b1} \text{ and } \chi_{b2})$ is found in the range of 0.20–2.9 and 0.05–2.0 eV.
**BB, BB*, and B*B* Cross-Sections**

- A new $b\bar{b}$-resonant structure, $\Upsilon(10750)$, observed by Belle in 2019 needs confirmation → Belle II collected $e^+e^-$ data at $\sqrt{s} = 10.653, 10.701, 10.746$ and 10.805 GeV and measure the $B^{(*)}B^{(*)}$ cross-sections for better understanding of $\Upsilon(10750)$.

- The $e^+e^- \rightarrow B^*B^*$ cross-section increases very rapidly just above the threshold (10.64852 GeV for $B^{++}B^{*-}$ and 10.65034 GeV for $B^{*0}\bar{B}^{*0}$).

- The fact suggests the existence of a $B^*B^*$ bound state near the $B^*B^*$ threshold.
### τ Mass

- Particle masses are fundamental parameters of the SM, and need to be measured with the highest precision. The precise determination of $M_\tau$ is important for LFU tests.

**Pseudo-endpoint $M_{\text{min}}$ method**

- $M_{\text{min}} \equiv \left[ M_{3\pi}^2 + 2(\sqrt{s}/2 - E_{3\pi}^*)(E_{3\pi}^* - p_{3\pi}^*) \right]^{1/2} \leq M_\tau$
  

- Perform an unbinned-maximum-likelihood fit of empirical distribution parameters including $M_\tau$ to the $M_{\text{min}}$ distribution.

\[
F(M_{\text{min}}) = 1 - P_2 \tan^{-1} \left( \frac{M_{\text{min}} - M_\tau}{P_1} \right) + P_3 (M_{\text{min}} - M_\tau) + P_4 (M_{\text{min}} - M_\tau)^2
\]

**$M_\tau$ fit result**

- $M_\tau = 1777.09 \pm 0.08 \pm 0.11$ MeV/c$^2$
  
  ... worlds’ most precise measurement.
Lepton Flavor Violating \( \tau^- \rightarrow \ell^- \phi \) Decay

- A vector leptoquark, which can accommodate for the LFU anomaly may enhance the \( \mathcal{B} \) of the LFV \( \tau^- \rightarrow e^- \phi(K^+K^-) \) and \( \mu^- \phi(K^+K^-) \) decays to a level of \( 10^{-11} \)-\( 10^{-8} \).

Event “reconstruction”

- Previous searches at Belle were conducted with tagged approach (\( \tau_{\text{tag}} \rightarrow \) one charged track + \( v \)).
- Increase the signal efficiency by dropping any requirement on \( \tau_{\text{tag}} \) and exploiting signal (\( \ell^-K^+K^- \)) and event kinematic features to BDT classifiers to suppress background \( \rightarrow \epsilon_{\text{sig}}^\mu = 6.5\% \sim 2 \times \text{Belle} \).

Poisson counting of signal events on the \( M_\tau-\Delta E_\tau \) plane

\[ \mathcal{B}(\tau^- \rightarrow e^- \phi) < 23 \times 10^{-8} \]
\[ \mathcal{B}(\tau^- \rightarrow \mu^- \phi) < 9.7 \times 10^{-8} \]
(\( @ 90\% \text{ CL} \))

Successful first application of untagged approach in \( \tau \)-pair analysis at Belle II
Charmed-Hadron Lifetimes

Debate on the charmed-baryon lifetimes

- The hierarchy of the charmed-baryon lifetimes, recently measured by LHCb, is different from old measurements. It suggests a revision of the higher order correction of the HQE.

### Pre-LHCb

\[ \tau_{\Omega_c^0} < \tau_{\Xi_c^-} < \tau_{\Lambda_c^+} < \tau_{\Xi_c^+} \]

### From LHCb results

\[ \tau_{\Xi_c^-} < \tau_{\Lambda_c^+} < \tau_{\Omega_c^0} < \tau_{\Xi_c^+} \]

**τ_{Ω_c^0} measurement at Belle II**

- \( e^+e^- \rightarrow c\bar{c}, \Omega_c^0 \rightarrow \Omega^-\pi^+, \Omega^- \rightarrow \Lambda^0 K^-, \Lambda^0 \rightarrow p\pi^- \).

Decay time:

\[ t = \frac{m_{\Omega_c^0} \vec{L} \cdot \vec{p}_{\Omega_c^0}}{|\vec{p}_{\Omega_c^0}|^2} \]

**Belle II preliminary**

Data (207 fb⁻¹)

- Fit
- Background

**Belle II preliminary**

Signal region

- Data
- Fit
- Background

**Decay-topology constrained vertex fit**

\[ \tau_{\Omega_c^0} = (243 \pm 48 \pm 11) \text{ fs} \]

... Belle II confirms the LHCb results

\( \tau_{D_s^+} \) result will come up soon.