Flavour Physics with Electroweak-Penguin and Semileptonic Decays at Belle II

Kazuki Kojima (Nagoya University)
on behalf of the Belle II collaboration

Light Cone 2021: Physics of Hadrons on the Light Front
Nov. 30th, 2021
The world's highest instantaneous luminosity: $3.1 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$

12 fb$^{-1}$/week, 40.3 fb$^{-1}$/month

(KKEB record: $2.1 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$, 8 fb$^{-1}$/week, 29.4 fb$^{-1}$/month)

Today's results: 34.6 fb$^{-1}$ or 62.8 fb$^{-1}$ at $\Upsilon(4S)$
The Belle II Detector

Substantially upgraded from the Belle detector except for calorimeter crystal and superconducting magnet

Equivalent or improved performances under higher beam background and event rate conditions. e.g. vertex resolution, $K_S^0$ reconstruction, $K/\pi$ identification, trigger system, ...

- **EM Calorimeter**: CsI(Tl), waveform sampling
- **Beryllium beam pipe**: 2cm diameter
- **Vertex Detector**: 2 layers DEPFET (pixel) + 4 layers Double-sided Silicon Strip Detector
- **Central Drift Chamber**: He(50%):C$_2$H$_6$(50%), Small cells, long lever arm, fast electronics
- **HER $e^-$**: 7 GeV
- **LER $e^+$**: 4 GeV
- **KL and muon detector**: Resistive Plate Counter (Outer barrel layers) Scintillator + Wavelength-shifting fiber + MPPC (Inner 2 layers of barrel & end-caps)
- **Particle Identification**: Time-of-Propagation counter (Barrel) Prox. focusing Aerogel RICH (Forward)
1. **Tagged Analysis**

One B meson from $\Upsilon(4S)$ decay is exclusively reconstructed to tag $B\bar{B}$ events.

2. **Untagged Analysis** (Inclusive Tagged Analysis)

Reconstruct only signal B decay and treat the other particles not in $B_{\text{sig}}$ as rest-of-event information.
1. **Tagged Analysis**

One B meson from \( \Upsilon(4S) \) decay is exclusively reconstructed to tag \( B \bar{B} \) events.

**Full Event Interpretation (FEI):**

Multivariate algorithm for exclusive tagging of one B meson in a \( \Upsilon(4S) \) decay using hierarchal approach.

Over 100 \( B \) meson decay channels and over 10,000 decay cascades

Improved efficiency up to 50% relatively with respect to conventional approaches!

2. **Untagged Analysis**

(Inclusive Tagged Analysis)

Reconstruct only signal B decay and treat the other particles not in \( B_{\text{sig}} \) as rest-of-event information.
$B$ Decay Reconstruction: Untagged Analysis

1. **Tagged Analysis**
   
   One $B$ meson from $\Upsilon(4S)$ decay is exclusively reconstructed to tag $B\bar{B}$ events.

2. **Untagged Analysis**
   (Inclusive Tagged Analysis)
   
   Reconstruct only signal $B$ decay and treat the other particles not in $B_{\text{sig}}$ as rest-of-event information.
Semileptonic Decays
Long standing tension ($\sim 3.3\sigma$) between inclusive and exclusive measurements of $|V_{cb}|$ and $|V_{ub}|$.

Anomalies (LFUV) in semitauonic decays:

$$R(D^{(*)}) = \frac{B(B \rightarrow D^{(*)}\tau\nu)}{B(B \rightarrow D^{(*)}\ell\nu)}, \ (\ell = e, \mu)$$
Untagged Exclusive $|V_{cb}|$ Measurements: $B \rightarrow D(\star)\ell\nu$

Measured branching ratios of $B^0 \rightarrow \bar{D}^{(\star)}\ell\nu$.

$$\cos \theta_{BY} = \frac{2E_B^* E_Y^* - m_B^2 - M_Y^2}{2|p_B^*|p_Y^*|}$$

Angle between nominal $B$ meson and $Y(= D^{(\star)}\ell)$ system

<table>
<thead>
<tr>
<th>Measured</th>
<th>PDG Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mathcal{B}(\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell)$</td>
<td>$(4.60 \pm 0.05_{\text{stat}} \pm 0.17_{\text{syst}} \pm 0.45_{\text{slow}}%)$</td>
</tr>
<tr>
<td>$\mathcal{B}(\bar{B}^0 \rightarrow D^0\ell^-\bar{\nu}_\ell)$</td>
<td>$(2.29 \pm 0.05_{\text{stat}} \pm 0.08_{\text{syst}}%)$</td>
</tr>
</tbody>
</table>

**Consistent within $1\sigma$**

In progress $|V_{cb}|$ measurement from differential BR in bins of hadron recoil parameter $w$
Measured branching ratios of $B^0 \to \overline{D}^{(*)}\ell\nu$.

Form factor parameters will be extracted with partial decay rates:

$$\Delta \Gamma_i = \frac{\text{Unfolded signal yield}}{N_{\text{signal},i} \times \mathcal{B}(D^{*+} \to D^0\pi^+) \times \mathcal{B}(D^0 \to K^-\pi^+)} \times \tau_{B^0}$$

Reconstruction efficiency and acceptance

* Not fit yet

In progress $|V_{cb}|$ measurement from differential BR in bins of hadron recoil parameter $w$
The branching fractions of four $B \to \pi \ell \nu / \rho \ell \nu$ channels were measured. The measured values are compared to the world average values. The $B^0 \to \pi^+ \ell^- \bar{\nu}_\ell$ channel has a measured significance of 6.2σ, while the $B^- \to \pi^0 \ell^- \bar{\nu}_\ell$ channel has a measured significance of 7.7σ. The $B^0 \to \rho^+ \ell^- \bar{\nu}_\ell$ channel has an upper limit of $< 3.37 \times 10^{-4}$ (95% CL), corresponding to a measured significance of 1.4σ. The $B^- \to \rho^0 \ell^- \bar{\nu}_\ell$ channel has an upper limit of $< 1.97 \times 10^{-4}$ (95% CL), corresponding to a measured significance of 1.5σ.

(*) Sum of three $q^2$ bins

Consistent with the world average

In progress: $|V_{ub}|$ measurement in $q^2$ bins, untagged exclusive measurement.
Untagged Inclusive $|V_{cb}|, |V_{ub}|$ Measurement: $B \to X\ell\nu$

Only a charged lepton is reconstructed explicitly and $X_{u,d}\ell\nu$ yields are extracted by fitting a $p_\ell^*$ distribution.

$B \to X_c\ell\nu$

Lepton momentum in the CM frame, $p_\ell^*$

$0.4 - 2.5$ GeV/c

$B \to X_c\ell\nu$

$B \to X_u\ell\nu$

2.1 - 2.8 GeV/c

$\mathcal{B}(B \to X_c\ell\nu) = (9.75 \pm 0.03_{\text{stat}} \pm 0.47_{\text{syst}})\%$

$B \to X_u\ell\nu$ excess at 3$\sigma$ level

In progress

Developing MVA to distinguish $b \to u$ and $b \to c$ events based on $M_X$ and rest-of-event information

K. Kojima (on behalf of the Belle II collaboration) / Light Cone 2021
Prospects of $R(D^{(*)})$ Measurements

Realized the measurement of branching fractions of $B \rightarrow D^*\ell\nu$, one of the normalization modes for

$$R(D^{(*)}) = \frac{\mathcal{B}(B \rightarrow D^{(*)}\tau\nu)}{\mathcal{B}(B \rightarrow D^{(*)}\ell\nu)}, \ (\ell = e, \mu),$$

at Belle II.

Hadronic FEI tag

$$\mathcal{B}(\bar{B}^0 \rightarrow D^{*+}\ell^{-}\bar{\nu}_\ell) = (4.60 \pm 0.41_{\text{stat}} \pm 0.27_{\text{syst}} \pm 0.45_{\text{slow}})\%$$

**In progress**

The analysis of $R(D^{(*)})$ with multiple channels

- Hadronic FEI tag, leptonic $\tau$ decays → First results by 2022 summer
- Hadronic FEI tag, hadronic $\tau$ decays
- Semileptonic FEI tag, leptonic $\tau$ decays

Inclusive $R(X) = \frac{\mathcal{B}(B \rightarrow X\tau\nu)}{\mathcal{B}(B \rightarrow X\ell\nu)}$ measurement

Unique measurement with hadronic FEI tag at Belle II !

→ First results in 2022

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**Observables and Uncertainties at 5 ab$^{-1}$**

<table>
<thead>
<tr>
<th>Observable</th>
<th>Uncertainties</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R(D^*)$</td>
<td>$(\pm 3.0_{\text{stat}} \pm 2.5_{\text{syst}})%$</td>
</tr>
<tr>
<td>$R(D)$</td>
<td>$(\pm 6.0_{\text{stat}} \pm 3.9_{\text{syst}})%$</td>
</tr>
</tbody>
</table>

Electroweak-Penguin Decays
Electroweak-penguin decays have flavor-changing neutral current (FCNC).

→ Sensitive to new physics (NP) beyond SM that contributes to FCNC process, suppressed in SM with one-loop diagrams.

Recently the LHCb experiment report new results of lepton flavor universality test in $b \rightarrow s \ell \ell$.  

Independent tests at Belle II are highly demanded!

**Electroweak-Penguin Decays & $R(K^{(*)})$ Anomalies**

JHEP 2018, 93 (2018)

$$R(K^{(*)}) = \frac{\mathcal{B}(B \rightarrow K^{(*)}\mu^+\mu^-)}{\mathcal{B}(B \rightarrow K^{(*)}e^+e^-)} = 1 \pm \mathcal{O}(10^{-2})$$

$q^2 \in [1(1.1), 6]$ for $R(K^{(*)})$

SM

NP

Preliminary Result of $B \rightarrow K\ell\ell$ at Belle II

$B \rightarrow K\ell\ell$ is studied toward the $R(K)$ measurements at Belle II.

- Electron can be reconstructed at an equivalent efficiency to muon at Belle II with a high purity.
- Momentum can be measured in the same way both for electrons and muons.

Signal yield: $8.6^{+4.3}_{-3.9} \text{stat} \pm 0.4 \text{syst}$

![Graph showing Mbc vs. Ldt = 62.8 fb⁻¹ for B⁺ → K⁺ l⁺ l⁻]

$M_{bc} = \sqrt{\frac{s}{4} - (p_B^*)^2}$

The measurement of $R(K^{(*)}) = \frac{B(B \rightarrow K^{(*)}\mu^+\mu^-)}{B(B \rightarrow K^{(*)}e^+e^-)}$ and $R(X_s) = \frac{B(B \rightarrow X_s\mu^+\mu^-)}{B(B \rightarrow X_s e^+e^-)}$

Not competitive to LHCb, but will be capable of independent check of the anomalies with $>5-10 \text{ ab}^{-1}$
Search for $B^+ \to K^+ \nu \bar{\nu}$ with an Inclusive Tagging Method

$b \to s \nu \bar{\nu}$ decays are not observed yet.

$\text{SM} : B(B^+ \to K^+ \nu \bar{\nu}) = (4.6 \pm 0.5) \times 10^{-6}$

Upper limit: $B(B^+ \to K^+ \nu \bar{\nu}) < 1.6 \times 10^{-5}$

Belle II performed the search for $B^+ \to K^+ \nu \bar{\nu}$ with an inclusive tagging method for the first time!


Train two BDTs in cascade to suppress backgrounds using event shape and rest-of-event information.

BDT$_1$ ... Discriminate signals mainly by topological features.
BDT$_2$ ... Improve purity of signals in events with BDT$_1$ > 0.9

$35\%$ increase at $4\%$ signal efficiency

$B^+ \to K^+ J/\psi \to K \mu^+ \mu^-$: Signal-like events (with dimuon mask)
$B^+ \to K^+ J/\psi \to K \mu^+ \mu^-$: Background-like events

BDT performance validation

arXiv:1409.4557
Search for $B^+ \rightarrow K^+ \nu \bar{\nu}$ with an Inclusive Tagging Method

Observed branching fraction:

$$\mathcal{B}(B^+ \rightarrow K^+ \nu \bar{\nu}) = \left( 1.9^{+1.3}_{-1.1} \text{stat} \pm 0.7 \text{syst} \right) \times 10^{-6}$$

Observed (expected) upper limit on the branching fraction:

$$\mathcal{B}(B^+ \rightarrow K^+ \nu \bar{\nu}) < 4.1 \times 10^{-5} \ (90\% \ CL)$$

Update of the $B^+ \rightarrow K^+ \nu \bar{\nu}$ analysis with more data,
Application of the inclusive tagging method e.g. to $B \rightarrow K^* \nu \bar{\nu}/K_S^0 \nu \bar{\nu}$, $B^+ \rightarrow \tau^+ \nu$

Competitive when the integrated luminosity is scaled to the previous results’!
20% and 350% improvement from the semileptonic and hadronic tagging method, respectively
Summary

Preliminary results are reported at early stage of Belle II with 34.6 or 62.8 fb\(^{-1}\) dataset for flavor physics studies with semileptonic decays and electroweak-penguin decays.

**Semileptonic decays:**

The analysis for \(|V_{cb}|\) and \(|V_{ub}|\) determination is ongoing.

Branching ratios of \(B \to D^{(*)}\ell\nu\), \(B \to \pi\ell\nu\), and \(B \to \rho\ell\nu\) (exclusive) and \(X_c\ell\nu\) (inclusive)

The inclusive and exclusive \(|V_{cb}|\) and \(|V_{ub}|\) tension will be addressed in the next years.

**Electroweak penguin decays:**

New inclusive tagged approach in \(B^+ \to K^+\nu\bar{\nu}\) shows high capability of the analysis.

Observed (expected) upper limit: \(\mathcal{B}(B^+ \to K^+\nu\bar{\nu}) < 4.1 \times 10^{-5}\) (90\% CL)

Working on the measurement of \(R(D^{(*)})\), \(R(X)\), \(R(K^{(*)})\) and \(R(X_s)\) to test lepton flavor universality in SM at Belle II.

Aiming for \(~800\) fb\(^{-1}\) by long shutdown in 2023 and \(50\) ab\(^{-1}\) over \(~10\) years.
Appendix
Long standing tensions ($\sim 3.3\sigma$) between inclusive and exclusive measurements of $|V_{cb}|/|V_{ub}|$
Multivariate algorithm for exclusive tagging of one B meson in a $\Upsilon(4S)$ decay using hierarchal approach with six stages of objects.

Over 100 $B$ meson decay channels and over 10,000 decay cascades

<table>
<thead>
<tr>
<th>Tagging Algorithm</th>
<th>Hadronic</th>
<th>Semileptonic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Reconstruction</td>
<td>0.28%/0.18%</td>
<td>0.67%/0.63%</td>
</tr>
<tr>
<td>FEI</td>
<td>0.78%/0.46%</td>
<td>1.80%/2.04%</td>
</tr>
</tbody>
</table>

The performance calibration is made with $B \rightarrow X\ell\nu$

$N_{X\ell\nu}$ is determined by the fit on $p_\ell^*$ distribution both in data and in MC.

$\epsilon_{\text{cal}} = \frac{N_{X\ell\nu}^\text{data}}{N_{X\ell\nu}^\text{MC}}$

$\epsilon_{\text{cal}}$ = 0.78% for hadronic $B^+$

$\epsilon_{\text{cal}}$ = 0.46% for hadronic $B^0$

### Hadronic tag
Reconstructing $B$ meson through $B^+/B^0$ modes and their daughter modes in the table

### Semileptonic tag
Reconstructing $B$ meson through $B \to D(\ast)\ell\nu$ or $B \to D(\ast)\pi\ell\nu$ with $D(\ast)$ modes in the table

#### Newly added in FEI
- Same as Full Reconstruction method in Belle

<table>
<thead>
<tr>
<th>$B^+$ modes</th>
<th>$B^0$ modes</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^+ \to D^0\pi^+$</td>
<td>$B^0 \to D^-\pi^+$</td>
</tr>
<tr>
<td>$B^+ \to D^0\pi^+\pi^0$</td>
<td>$B^0 \to D^-\pi^+\pi^0$</td>
</tr>
<tr>
<td>$B^+ \to D^0\pi^+\pi^0\pi^0$</td>
<td>$B^0 \to D^-\pi^+\pi^+\pi^-$</td>
</tr>
<tr>
<td>$B^+ \to D^0\pi^+\pi^0\pi^-$</td>
<td>$B^0 \to D^-\pi^+\pi^-\pi^0$</td>
</tr>
<tr>
<td>$B^+ \to D^0\pi^+\pi^+\pi^+\pi^-$</td>
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</tr>
<tr>
<td>$B^+ \to D^0\pi^+\pi^+\pi^-\pi^0$</td>
<td>$B^0 \to D^-\pi^+\pi^-\pi^0\pi^-$</td>
</tr>
<tr>
<td>$B^+ \to D^0\pi^+\pi^+\pi^-\pi^0\pi^0$</td>
<td>$B^0 \to D^-\pi^+\pi^-\pi^-\pi^0\pi^0$</td>
</tr>
<tr>
<td>$B^+ \to D^0\pi^+\pi^+\pi^-\pi^-\pi^0\pi^0$</td>
<td>$B^0 \to D^-\pi^+\pi^-\pi^-\pi^-\pi^0\pi^0$</td>
</tr>
</tbody>
</table>

#### Newly added in FEI
- Same as Full Reconstruction method in Belle

<table>
<thead>
<tr>
<th>$D^+$, $D^{*+}$, $D_s^+$ modes</th>
<th>$D^0, D^{*0}$ modes</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^+ \to K^-\pi^+\pi^0$</td>
<td>$D^0 \to K^-\pi^+\pi^0$</td>
</tr>
<tr>
<td>$D^+ \to K^-\pi^+\pi^+\pi^0$</td>
<td>$D^0 \to K^-\pi^+\pi^+\pi^0$</td>
</tr>
<tr>
<td>$D^+ \to K^-\pi^+\pi^+\pi^-\pi^0$</td>
<td>$D^0 \to K^-\pi^+\pi^+\pi^-\pi^0$</td>
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<tr>
<td>$D^+ \to K^-\pi^+\pi^+\pi^-\pi^-\pi^0$</td>
<td>$D^0 \to K^-\pi^+\pi^+\pi^-\pi^-\pi^0$</td>
</tr>
<tr>
<td>$D^+ \to K^-\pi^+\pi^+\pi^-\pi^-\pi^-\pi^0$</td>
<td>$D^0 \to K^-\pi^+\pi^+\pi^-\pi^-\pi^-\pi^0$</td>
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<td>$D^+ \to K^-\pi^+\pi^+\pi^-\pi^-\pi^-\pi^-\pi^0$</td>
<td>$D^0 \to K^-\pi^+\pi^+\pi^-\pi^-\pi^-\pi^-\pi^0$</td>
</tr>
</tbody>
</table>

- Newly added in FEI
**$R(D^{(*)})$ Measurement with FEI at Belle**

Measurement of $R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}\ell\nu)}$, ($\ell = e, \mu$) at Belle.

with the semileptonic tag of $B \to D^{(*)}\ell\nu$ channels by Full Event Interpretation and leptonic $\tau$ decays.

Extracted the yields of signal and normalization modes from a two-dimensional extended maximum likelihood fit to the variables $E_{ECL}$ and $O_{\text{classifier}}$.

$E_{ECL}$ (sum of extra energy not used for the reconstruction) distributions with $O_{\text{classifier}} > 0.9$

<table>
<thead>
<tr>
<th>Observable</th>
<th>Measured</th>
<th>SM Prediction</th>
<th>Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R(D^*)$</td>
<td>$(0.283 \pm 0.018_{\text{stat}} \pm 0.014_{\text{syst}})$%</td>
<td>$(0.258 \pm 0.003)$%</td>
<td>$1.1\sigma$</td>
</tr>
<tr>
<td>$R(D)$</td>
<td>$(0.307 \pm 0.037_{\text{stat}} \pm 0.016_{\text{syst}})$%</td>
<td>$(0.299 \pm 0.003)$%</td>
<td>$0.2\sigma$</td>
</tr>
</tbody>
</table>

XGBoost with three input variables: $\cos \theta_{B,D^{(*)}\ell}$, the approximate missing mass squared $m^2_{\text{miss}} = (E_{e^+e^-} - E_{D^{(*)}} - E_{\ell})^2 - (\vec{p}_{D^{(*)}} - \vec{p}_{\ell})^2$, and the visible energy $E_{\text{vis}} = \sum_i E_i$.
An irreducible systematic uncertainty of 0.5% for the optimistic one is assumed. The optimistic scenario also assumes 50% increase in the reconstruction efficiency of the exclusive tagging algorithms.
### Status & Projection

#### Status in 2019

#### Belle II Projection

**LHCb Projection**

*arXiv:1808.08865*

1.1 < \( q^2 \) < 6.0 GeV^2/c^4

### Table 7.2: Estimated yields of \( b \rightarrow se + e \) and \( b \rightarrow de + e \) processes and the statistical uncertainty on \( R_X \) in the range 1.1 < \( q^2 \) < 6.0 GeV^2/c^4 extrapolated from the Run 1 data. A linear dependence of the \( b \rightarrow p \) production cross section on the pp centre-of-mass energy and unchanged Run 1 detector performance are assumed. Where modes have yet to be observed, a scaled estimate from the corresponding muon mode is used.

<table>
<thead>
<tr>
<th>Process</th>
<th>Yield Run 1</th>
<th>Result</th>
<th>9 fb^{-1}</th>
<th>23 fb^{-1}</th>
<th>50 fb^{-1}</th>
<th>300 fb^{-1}</th>
</tr>
</thead>
<tbody>
<tr>
<td>( B^+ \rightarrow K^+ e^+ e^- )</td>
<td>254 ( \pm ) 29</td>
<td>1120</td>
<td>300</td>
<td>750</td>
<td>46000</td>
<td></td>
</tr>
<tr>
<td>( B^0 \rightarrow K^0 e^+ e^- )</td>
<td>111 ( \pm ) 14</td>
<td>490</td>
<td>1400</td>
<td>3000</td>
<td>20000</td>
<td></td>
</tr>
<tr>
<td>( B^0_s \rightarrow e^+ e^- )</td>
<td>(-80) ( \pm ) 230</td>
<td>530</td>
<td>3000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \phi \rightarrow K^+ e^+ e^- )</td>
<td>(-120) ( \pm ) 360</td>
<td>820</td>
<td>5000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( K^0 \rightarrow \pi^+ e^+ e^- )</td>
<td>(-20) ( \pm ) 70</td>
<td>150</td>
<td>900</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( K^+ \rightarrow \pi^+ e^+ e^- )</td>
<td>(-105) ( \pm ) 360</td>
<td>820</td>
<td>5000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( K^0 \rightarrow \pi^+ e^+ e^- )</td>
<td>(-30) ( \pm ) 175</td>
<td>900</td>
<td>5000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Figure 7.6: Constraints on the difference in the \( C_9 \) and \( C_{10} \) Wilson coefficients from electron and muon modes with the Run 3 and Upgrade II data sets. The 3 regions for the Run 3 data sample are shown for the SM (solid blue), a vector-axial-vector new physics contribution (red dotted) and for a purely vector new physics contribution (green dashed). The shaded regions denote the corresponding constraints for the Upgrade II data set.

The line is a fit to the Run 3 data set. The SM is defined only up to \( C_3 = 1 \). The two Run 3 data sets are consistent within uncertainties.

This approach is expected to work well, even with very large data sets.

Other sources of systematic uncertainty can be mitigated through design choices for the upgraded detector. The recovery of bremsstrahlung photons is inhibited by the ability to find the relevant photons in the ECAL (over significant backgrounds) and by the energy resolution. A reduced amount of material before the magnet would reduce the amount of bremsstrahlung and hence would increase the electron reconstruction efficiency and improve the contamination of the final state electrons with K decay electrons.
$R(X_s)$ Projection

$$R(X_s) = \frac{\mathcal{B}(B \to X_s \mu^+ \mu^-)}{\mathcal{B}(B \to X_s e^+ e^-)}$$

<table>
<thead>
<tr>
<th>Observables</th>
<th>Belle 0.71 ab$^{-1}$</th>
<th>Belle II 5 ab$^{-1}$</th>
<th>Belle II 50 ab$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{X_s}$ ([1.0, 6.0] GeV$^2$)</td>
<td>32%</td>
<td>12%</td>
<td>4.0%</td>
</tr>
<tr>
<td>$R_{X_s}$ (&gt; 14.4 GeV$^2$)</td>
<td>28%</td>
<td>11%</td>
<td>3.4%</td>
</tr>
</tbody>
</table>
A spin-1 SU(2)$_L$ singlet leptoquark $U_1$ with one loop and $Z'$ exchange at tree level can be considered as new physics contributions in the transition of $b \rightarrow s \nu \bar{\nu}$.

Effective Lagrangian of $b \rightarrow s \nu \bar{\nu}$:

$$\mathcal{L}_{b \rightarrow s \nu \bar{\nu}} = -\frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} C_{\nu}^{\alpha \beta} (\bar{s}_L \gamma_\mu b_L) (\bar{\nu}_L^\alpha \gamma^\mu \nu_L^\beta)$$

Due to the underlying $U(2)^5$ flavor structure, NP effects are dominant in the Wilson coefficient involving the third family,

$$C_{\nu, NP}^{\tau \tau} = C_{\nu, Z'}^{\tau \tau} + C_{\nu, U}^{\tau \tau}.$$

The NP correction to the $B \rightarrow K^{(*)}\nu \bar{\nu}$ branching ratio:

$$\frac{\mathcal{B}(B \rightarrow K^{(*)}\nu \bar{\nu})}{\mathcal{B}(B \rightarrow K^{(*)}\nu \bar{\nu})_{SM}} \approx \frac{2}{3} + \frac{1}{3} \left| \frac{C_{\nu, NP}^{\tau \tau} + C_{\nu, SM}^{\tau \tau}}{C_{\nu, SM}^{\tau \tau}} \right|^2$$

Current experimental limits:

$$\frac{\mathcal{B}(B \rightarrow K\nu \bar{\nu})}{\mathcal{B}(B \rightarrow K\nu \bar{\nu})_{SM}} = 2.4 \pm 0.9, \quad \frac{\mathcal{B}(B \rightarrow K^*\nu \bar{\nu})}{\mathcal{B}(B \rightarrow K^*\nu \bar{\nu})_{SM}} < 3.2 \ (95\% \ CL)$$
The uncertainties on $N_{B^0/±}$, lepton ID, tracking, continuum shape will be reducible by evaluation with more data.

- $N_{B^0/±}$: **BELLE2-NOTE-PL-2019-017**
- Lepton ID performance: **BELLE2-CONF-PH-2021-002**
- Tracking: **BELLE2-NOTE-PL-2020-014**
Systematics on Tagged Exclusive $B \to \pi \ell \nu / \rho \ell \nu$

For $B \to \pi \ell \nu$ decays, the systematic uncertainties from the modeling of $B \to X_u \ell \nu$ are expected to be small compared to other systematic uncertainties.

For $B \to \rho \ell \nu$ decays, the uncertainty on the non-resonant model cannot be quantified with the currently available dataset, but is expected to be small compared to the statistical uncertainties.

Additional systematic uncertainties on the efficiencies of various selection criteria are not included, as these are expected to be considerably small in comparison to other systematic effects.
Each branching fraction of 30 separate decay mode in inclusive samples is varied by $\pm 1\sigma$ of the current average branching fraction at the fit. The full modeling uncertainty is calculated by adding the separate contributions in quadrature.

The form factor uncertainty is estimated by assuming the Caprini, Lellouch and Neubert (CLN) parameterization for the $B \to D^* \ell \nu$ and $B \to D \ell \nu$ decays and varying the form factor parameters within their ranges of uncertainty.
Systematics on Tagged Exclusive $B \rightarrow D^{(*)}\ell\nu$

<table>
<thead>
<tr>
<th>Source</th>
<th>Relative uncertainty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracking of $\pi_s$</td>
<td>10%</td>
</tr>
<tr>
<td>MC modeling</td>
<td>5%</td>
</tr>
<tr>
<td>FEI Calibration</td>
<td>3%</td>
</tr>
<tr>
<td>Tracking of $K, \pi, \ell$</td>
<td>3%</td>
</tr>
<tr>
<td>$N_{B^0}$</td>
<td>2%</td>
</tr>
<tr>
<td>$f_{+0}$</td>
<td>1%</td>
</tr>
<tr>
<td>Charm branching fractions</td>
<td>1%</td>
</tr>
<tr>
<td>Lepton ID</td>
<td>1%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>12%</strong></td>
</tr>
</tbody>
</table>

← MC sample size 100 fb$^{-1}$
Systematics on $B^+ \rightarrow K^+ \nu\nu$

The leading systematic uncertainty is the normalization uncertainty on the background yields.

- Each of background yields is constrained assuming a normal constraint, centered at the expected background yield obtained from simulation
- The background yields can be varied in the fit within a standard deviation corresponding to 50% of the central value.

Three nuisance parameters each to model correlations between the individual SR and CR bins
- The energy miscalibration of hadronic and beam-background calorimeter energy deposits
- The tracking inefficiency
One nuisance parameter each
- The systematic uncertainty due to the limited size of simulated samples
One nuisance parameter per bin per background category → 175 nuisance parameters in total

a global normalization difference of $(40 \pm 12)\%$ between the off-resonance data and simulation in the control regions CR2 and CR3
+ the uncertainty on the sample luminosity

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+ the uncertainty on the sample luminosity
Tagged Inclusive $|V_{cb}|$ Measurement: $B \rightarrow X_c \ell \nu$

$|V_{cb}|$ is extracted using the branching fraction as well as spectral moments based on the Heavy Quark Expansion (HQE) up to $\mathcal{O}(1/m_b^3)$.

Measured the first six hadronic mass moments, $\langle M_X \rangle$ to $\langle M_X^6 \rangle$, with the hadronic FEI tag.

\[
\langle M_X^n \rangle = \frac{\sum_i w_i(M_X)M_{X,\text{calib}}^n}{\sum_i w_i(M_X)} \times C_{\text{calib}} \times C_{\text{true}}
\]

Calibration bias
Reconstruction bias

The analysis of leptonic invariant mass ($q^2$) spectrum

$\rightarrow$ Fully data-driven $|V_{cb}|$ determination up to $\mathcal{O}(1/m_b^4)$ with a novel approach [JHEP02(2019)177].

Observed $M_X$
Tagged Exclusive $|V_{cb}|$ Measurements: $B \rightarrow D^* \ell \nu$

Measured branching fractions of $B \rightarrow D^* \ell \nu$.

$$M_{\text{miss}}^2 = (p_{e^-} - p_{B_{\text{tag}}} - p_{D^*} - p_{\ell})^2$$

This analysis mode is used as a normalization mode of $R(D^{(*)}) = \frac{B(B \rightarrow \bar{D}^{(*)} \tau \nu)}{B(B \rightarrow D^{(*)} \ell \nu)}$, ($\ell = e, \mu$)

Hadronic FEI tag

<table>
<thead>
<tr>
<th>Had. FEI tagged</th>
<th>Measured</th>
<th>PDG Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>($4.60 \pm 0.41_{\text{stat}} \pm 0.27_{\text{syst}} \pm 0.45_{\pi_{\text{slow}}}$)%</td>
<td>($5.05 \pm 0.14$)%</td>
<td></td>
</tr>
</tbody>
</table>

| Untagged              | ($4.60 \pm 0.05_{\text{stat}} \pm 0.17_{\text{syst}} \pm 0.45_{\pi_{\text{slow}}}$)% |

In progress $|V_{cb}|$ measurement from differential BR in bins of hadron recoil parameter $w$

K. Kojima (on behalf of the Belle II collaboration) / Light Cone 2021
Challenging due to large background from $X_c \ell \nu$.

→ Exploit the endpoint of the electron momentum, $p^*$. The $b \to c$ component becomes negligible above 2.4 GeV/c.

Observed $B \to X_u e\nu$ excess at 3σ level.

→ Capable of measuring $|V_{ub}|$ with more data.

In progress

Developing MVA to distinguish $b\to u$ from $b\to c$ events based on $M_X$ and rest-of-event information

2021/11/30 K. Kojima (on behalf of the Belle II collaboration) / Light Cone 2021