Rare decays studies using early Belle II data

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(Tokyo Metropolitan University)
on behalf of the Belle II collaboration

BEAUTY 2019
18th INTERNATIONAL CONFERENCE ON B-PHYSICS AT FRONTIER MACHINES
Ljubljana, Slovenia
September 30 - October 4, 2019
Outline

• Introduction
  – Belle II experiment
  – Rare decays

• Rare decays at early Belle II
  – $B \rightarrow K^*\gamma$
  – $B \rightarrow K\pi$
  – Prospects

• Summary
Outline

- **Introduction**
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  - Prospects
- **Summary**
New physics search

**Energy frontier**
~direct approach~

- SM
- NP

Directly produce new particles using high energy collision.

Sensitive to the energy scale of NP.

**Luminosity frontier**
~indirect approach~

- SM
- NP

Find signatures of new particles in the intermediate state.

Sensitive to the flavor structure of NP.

The Belle II experiment is a luminosity frontier experiment.
The Belle II experiment

The Belle experiment
- KEKB accelerator
- Belle detector

The Belle II experiment
- SuperKEKB accelerator
- Belle II detector

Search for new physics beyond the Standard Model with high statistics data up to 50 ab$^{-1}$ integrated luminosity.
The SuperKEKB accelerator

- Asymmetric beam energy
  - $e^{-}(7 \text{ [GeV]})$ and $e^{+}(4 \text{ [GeV]})$
  - $e^{-} \rightarrow e^{+} \Rightarrow \Upsilon(4S) \Rightarrow B\bar{B}$

- Boosted $B\bar{B}$ pairs
  - Lorentz factor: $\beta \gamma = 0.28$
  - Target luminosity: $8 \times 10^{35} \text{ [cm}^{-2}\text{s}^{-1}]$
  - Luminosity at KEKB ×40

2019/10/1
The Belle II detector

- General purpose spectrometer
- Seven sub-detectors
- \( \approx 4\pi \) acceptance
- 30 kHz readout
- High background resistance
- Good particle identification

Belle II TDR, arXiv:1011.0352
[Feb. ~ June 2016] Phase 1: beam background study w/o Belle II detector

[March ~ July 2018] Phase 2: Belle II detector w/o VXD
First collision!

[March ~ June 2019] Phase 3: Full Belle II detector
First physics run with full Belle II detector

**Phase 3 run summary**
- Collected 6.5 fb\(^{-1}\) with full Belle II detector
- Peak Lumi. at data taking
  - \(L_{\text{peak}} = 5.5 \times 10^{33} \text{ cm}^{-2}\text{sec}^{-1}\)
- Lumi. challenge (SuperKEKB peak)
  - \(L_{\text{peak}} = 1.2 \times 10^{34} \text{ cm}^{-2}\text{sec}^{-1}\)

We have started to look into various physics processes.

**Total \(\int \mathcal{L} \, dt = 6.49 \text{ [fb}^{-1}\)**
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Rare decays

- Rare decays have high sensitivity to search new physics.
  - New physics contributes in loops or new tree diagrams.
- Some new physics models contribute some of rare decays.
  - New physics model can be identified by patterns of deviation from SM.

<table>
<thead>
<tr>
<th>Observables</th>
<th>Experimental Sensitivity</th>
<th>Multi-Higgs Models (§17.2)</th>
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<tbody>
<tr>
<td>$b \to s$ EW penguins:</td>
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<td>$\Delta A_{CP}(B \to K^{(*)}\pi)$</td>
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<td>Radiative Penguins:</td>
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<td>$B(B \to X_s \gamma)$</td>
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<td>$A_{CP}(B \to X_{s+d} \gamma)$</td>
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<td>$S_{CP}(B^0_d \to K^0_S \pi^0 \gamma)$</td>
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<td>$B^0_s \to \eta^{(')}\gamma$ lifetime</td>
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★★★ : Sensitive
★★ : Moderate effect
★ : Small effect
☐ : No specific study
× : No significant contribution

Measurement of rare decays are important to search new physics.
Rare decays

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Semileptonic $b \to s$ Penguin Decays:

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<tr>
<th>$B \to K^{(*)}\ell\ell$ angular</th>
<th>**</th>
<th>x</th>
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<tr>
<td>$R(K^*)$, $R(K)$</td>
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<td>$\mathcal{B}(B \to X_s\ell\ell)$</td>
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<td>$\mathcal{B}(B \to K^{(*)}\tau\tau)$</td>
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<td>$\mathcal{B}(B \to K^{(*)}\nu\nu)$</td>
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There are many rare decays
- Radiative and electroweak penguin
- Charmless hadronic
- etc.

Today, two decay studies will be shown.
- $B \rightarrow K^*\gamma$
  - $b \rightarrow s$ radiative penguin
  - Most major mode in radiative B decay.
- $B \rightarrow K\pi$
  - $b \rightarrow s$ penguin + $b \rightarrow u$ tree
  - Direct CP
  - Most major mode in charmless hadronic B decay.
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$B \to K^{*\gamma}$ status

- Flavor changing neutral current (FCNC)
  
  $- b \to s\gamma$ process

  $\mathcal{B}(B^0 \to K^{*0}\gamma) = (3.96 \pm 0.07 \pm 0.14) \times 10^{-5}$

  $\mathcal{B}(B^+ \to K^{*+}\gamma) = (3.76 \pm 0.10 \pm 0.12) \times 10^{-5}$

  $\Delta_{0+} = (+6.2 \pm 1.5 \pm 0.6 \pm 1.2)\%$

  Uncertainties
  first: statistical
  second: systematic
  third: $f_{+}/f_{00}$

- Isospin violation.
  
  - Evidence: $3.1\sigma$
  
  - Constrain mSUGRA parameter space.

Isospin violation can be found with $>5\sigma$ precision at Belle II.
$B \rightarrow K^*\gamma$ results at Belle II

- Search $B \rightarrow K^*\gamma$ decay using three decay modes

  $- B^0 \rightarrow K^{*0}(\rightarrow K^+\pi^-)\gamma$
  $- B^+ \rightarrow K^{*+}(\rightarrow K^+\pi^0)\gamma$
  $- B^+ \rightarrow K^{*+}(\rightarrow K_S^0\pi^+)\gamma$

\[
\int L \, dt = 2.62 \text{ fb}^{-1}
\]

- Distribution of beam energy constrained mass $m_{bc} = \sqrt{E_{beam}^2 - p_B^*^2}$
  clear peak is seen at $m_B = 5.28 \text{ GeV}/c^2$

- Signal yield and significance is obtained by fitting. → next page
$B \to K^{*}\gamma$ signal yield extraction

- Yields agree with WA branching fractions.
- Combined significance exceeds 5 $\sigma$.

Rediscovery of penguin decay at Belle II
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\( B \rightarrow K\pi \) status

- Charmless hadronic B decay
- \( \Delta A_{CP} \) puzzle: 5.6 \( \sigma \) discrepancy of the difference of CP asymmetry.
  
  \[- A_{CP}(K^+\pi^-) = - 0.082 \pm 0.006 \]
  
  \[- A_{CP}(K^+\pi^0) = + 0.040 \pm 0.021 \]

- Isospin sum rule can identify NP or not

\[
I_{K\pi} = A_{CP}(K^+\pi^-) + A_{CP}(K^0\pi^+) \frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}K^+\pi^-} \cdot \frac{\tau_0}{\tau_+}
\]

\[
-A_{CP}(K^+\pi^0) \frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}K^+\pi^-} \cdot \frac{\tau_0}{\tau_+} - A_{CP}(K^0\pi^0) \frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}K^+\pi^-}
\]

- If \( I_{K\pi} \neq 0 \), effect of NP in EW penguin.
- \( I_{K\pi} = -14 \pm 11 \% \) (WA)

Need more statistics for precise measurement.
$B \to K\pi$ results at Belle II

- Search $B \to K\pi$ decay using following decay mode.
  
  $B^0 \to K^\pm \pi^\mp$

![Graph showing candidates per 1.6 MeV/c^2 vs M_{bc} [GeV/c^2] with data, B^0 \to h^+h^-$, and background for Belle II 2019 (preliminary).](image)

$\int L \, dt = 5.15 \text{ fb}^{-1}$

yield: 26.3±6.2, significance: 5.46 $\sigma$

First signal of charmless hadronic B decay at Belle II.

2019/10/1
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Prospects for $B \to K^* ll$

- $b \to sll$ process
  - loop or box diagram
- Anomaly of lepton universality: 2.4-2.5 $\sigma$ from SM
  - Latest Belle result is compatible with previous measurement.

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

$\delta R(K^*)$ includes both statistics and systematic uncertainty.

Expect to verify the lepton universality violation.
Prospects

- Primary goal: collect $L_{int} = 50 \text{ ab}^{-1}$
- Current status: very early stage with $L_{int} = 6.5 \text{ fb}^{-1}$

$B \rightarrow K^*\gamma$: verify isospin violation
$B \rightarrow K\pi$: verify isospin sum rule
$B \rightarrow K^*ll$: verify lepton universality violation
$B \rightarrow h\nu\bar{\nu}$: can be observed etc.

We will provide many results.
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Summary

- Belle II have started collecting beam collision data.
  - Collected 6.5 fb\(^{-1}\) integrated luminosity.
- Rare decays are important to search new physics.
- Studies of various processes have been started.
  - Rediscovered \(B \rightarrow K^*\gamma\) decay.
  - Signal for first charmless hadronic B decay.
- We are searching new physics with rare decays.
  - We will show many results.

stay tuned!
Thank you for your attention!
Back up
SuperKEKB

KEKB→SuperKEKB

- LER (3.5 GeV → 4.0 GeV)
  - longer Touschek lifetime
- HER (8.0 GeV → 7.0 GeV)
  - Lower emittance beam
  - Lower Synchrotron radiation loss
- Luminosity ×40
  - smaller beams ×20
  - large currents ×2

<table>
<thead>
<tr>
<th></th>
<th>KEKB LER/HER</th>
<th>SuperKEKB LER/HER</th>
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</thead>
<tbody>
<tr>
<td>E [GeV]</td>
<td>3.5/8.0</td>
<td>4.0/7.0</td>
</tr>
<tr>
<td>$\beta_y$ at IP [mm]</td>
<td>5.9/5.9</td>
<td>0.27/0.30</td>
</tr>
<tr>
<td>I [A]</td>
<td>1.6/1.2</td>
<td>3.6/2.6</td>
</tr>
<tr>
<td>Lifetime [min]</td>
<td>130/200</td>
<td>~10</td>
</tr>
<tr>
<td>crossing angle [mrad]</td>
<td>22</td>
<td>83</td>
</tr>
<tr>
<td>L [cm$^{-2}$s$^{-1}$]</td>
<td>$2.1 \times 10^{34}$</td>
<td>$80 \times 10^{34}$</td>
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</table>

Major upgrades

- beam pipe
- $e^+$ source
- positron damping ring
- QCS for nano-beam scheme
- IR design etc.
SuperKEKB

“Nano-beam" scheme

Continuous beam injection (started from 14th, May)
**Vertexing**

Beampipe: $r = 10 \text{ mm}$

DEPFET pixels
- Layer 1: $r = 14 \text{ mm}$
- Layer 2: $r = 22 \text{ mm}$

Double sided silicon detectors
- Layer 3: $r = 38 \text{ mm}$
- Layer 4: $r = 80 \text{ mm}$
- Layer 5: $r = 115 \text{ mm}$
- Layer 6: $r = 140 \text{ mm}$

VXD resolution in impact parameter $\sim 14 \mu\text{m}$. 
Particle identification

Barrel: Time of Propagation (TOP)
forward endcap: Aerogel RICH (ARICH)

**ARICH principle**

- **π**
- **K**

- **20 cm**
- **~6 cm**

**TOP principle**

- **incoming track**
- **Photon from π⁺**
- **Photon from K⁺**

K efficiency and π mis-ID by combining CDC dE/dx, TOP and ARICH.

\[ D^{*+} \rightarrow D^0\pi^+; \quad D^0 \rightarrow K^\pi^+ \]
Long term prospects

- **B→η'K_s new CP**
- **Confirm B→D^*τν new physics**
- **Resolve |V_{ub}| puzzle**
- **ee→A'(χχ)γ** precision for (g-2)μ
- **B→μν discovery**
- **τ LFV discovery**
- **W_R in B→ργ**
- **B→KVV SM discovery**
- **B→Kee LFUV new physics**

All the details are in “The Belle II Physics Book” E. Kou, P. Urquijo et al..

https://inspirehep.net/record/1692393/
*B \rightarrow K^{*\gamma}* measurement at Belle

Simultaneous fit to $m_{bc}$ distribution in 7 categories to extract branching fraction and asymmetries

Fit results

$\mathcal{B}(B^0 \rightarrow K^{0\gamma}) = (3.96 \pm 0.07 \pm 0.14) \times 10^{-5}$

$\mathcal{B}(B^+ \rightarrow K^{+\gamma}) = (3.76 \pm 0.10 \pm 0.12) \times 10^{-5}$

$A_{CP}(B^0 \rightarrow K^{0\gamma}) = (-1.3 \pm 1.7 \pm 0.4) \%$

$A_{CP}(B^+ \rightarrow K^{+\gamma}) = (+1.1 \pm 2.3 \pm 0.3) \%$

$\Delta_{0^+} = (+6.2 \pm 1.5 \pm 0.6 \pm 1.2) \%$

$\Delta A_{CP} = (+2.4 \pm 2.8 \pm 0.5) \%$

$\bar{A}_{CP} = (-0.1 \pm 1.4 \pm 0.3) \%$
$B \to K\pi$

diagrams for $B^+ \to K^+\pi^0$ decay

- C and $P_{EW}$ are expected to be negligible in SM.
  - Enhancement of C? $\to$ breakdown of theoretical understanding
  - Enhancement of $P_{EW}$? $\to$ would include new physics
$B \to h\nu\bar{\nu}$

Not observed yet: factor 2 above SM expectation
→ can be observed at Belle II