Status of the Belle II experiment and prospects for $B$ and $\tau$ Physics

Chengping Shen

MASS2018: Origin of Mass at the High Energy and Intensity Frontier, May 28 - June 1, 2018, Denmark
Due to limited time, I will only give highlights on some topics which will be studied at Belle II. Apologies if I neglect your favorite topics.
B-physics in the last decade

- Belle and BaBar have produced a large number of important results, since the beginning of their data taking.
- Competition between the two experiments has helped in pulling out the best from the two datasets.

The Physics of B factories
EPJC 74, 3026 (2018)

Belle II will provide a significantly larger data sample (x50 Belle) that will allow to continue the investigation with a much more powerful instrument.
\( \tau \)-physics in the last decade

\((\sim 0.9 \times 10^9 \tau^+\tau^-\text{ pairs per ab}^{-1})\)

NP hunting: SM suppressed decay searches have reached limits down to \(10^{-7} \sim 10^{-8}\).

**SM:** \((\text{Phys. Rev. D16 (1977) 1444})\)

\[
\mathcal{B}(\tau \to l\gamma) = \frac{3\alpha}{32\pi} \left| \sum_i U^*_{\tau i} U_{\mu i} \frac{\Delta_{3i}^2}{m_W^2} \right|^2 \leq 10^{-53} \sim 10^{-49}
\]

**NP:**

\[
\mathcal{B}(\tau \to \mu\gamma) \simeq (4.5 \times 10^{-6}) \left| (\delta_{LL})_{32} \right|^2 \left( \frac{500 \text{ GeV}}{m_{\text{SUSY}}} \right)^4 \left( \frac{\tan \beta}{10} \right)^2
\]

Calibbi et al., PRD 74, 116002 (2006)

Hadronic decays of \(\tau\) offer unique tools for the precise study of low energy QCD, CP violation is also searched for
Complementarity to LHCb

- Clean environment
  - Efficient detection of neutrals ($\gamma$, $\pi^0$, $\eta$, …)
- Quantum correlated $B^0\bar{B}^0$ pairs
  - High effective flavor tagging efficiency:
    $\sim 34\%$ (Belle II) $\leftrightarrow \sim 3\%$ (LHCb)
- Large sample of $\tau$ leptons
  - Search for LFV $\tau$ decays at $O(10^{-9})$

Full reconstruction tagging possible
- A powerful tool to measure;
  - $b\to u$ semileptonic decays (CKM)
  - decays with large missing energy
  - etc.

Systematics different from LHCb
- Two experiments are required to establish NP
  - Large cross section and decays to all charged particles

$B \to \pi \gamma \nu$
$B \to \tau \nu, D \tau \nu$
$B \to K \nu \nu$
The Physics Program

- a (Super) B-factory ($\sim 1.1 \times 10^9 \text{ B}\bar{B} \text{ pairs per ab}^{-1}$);
- a (Super) charm factory ($\sim 1.3 \times 10^9 \text{ c}\bar{c} \text{ pairs per ab}^{-1}$);
- a (Super) $\tau$ factory ($\sim 0.9 \times 10^9 \tau^+\tau^- \text{ pairs per ab}^{-1}$);
- thanks to the Initial State Radiation, we can effectively scan the range [0.5 – 10] GeV and measure the $e^+e^- \rightarrow \text{light hadrons}$ cross-section very precisely;
Need $O(100x)$ more data $\rightarrow$ Next generation B-factories

**Peak Luminosity Trends ($e^+e^-$ collider)**

- **SuperKEKB**
- **KEKB**
- **PEP-II**

40 times higher luminosity

8 x $10^{35}$
High-Luminosity Asymmetric B Factory

- Target luminosity is $\mathcal{L} = 8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$ (x40 w.r.t. BELLE)
- Achievable in the *nano-beam scheme* (P. Raimondi for SuperB)
  - double beam currents
  - squeeze beams @ IP by 1/20

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<table>
<thead>
<tr>
<th>parameters</th>
<th>KEKB LER</th>
<th>KEKB HER</th>
<th>Super-KEKB LER</th>
<th>Super-KEKB HER</th>
<th>units</th>
</tr>
</thead>
<tbody>
<tr>
<td>beam energy</td>
<td>$E_b$</td>
<td>3.5</td>
<td>8</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>CM boost</td>
<td>$\beta_\gamma$</td>
<td>0.425</td>
<td></td>
<td>0.28</td>
<td></td>
</tr>
<tr>
<td>half crossing angle</td>
<td>$\varphi$</td>
<td>11</td>
<td></td>
<td>41.5</td>
<td>mrad</td>
</tr>
<tr>
<td>horizontal emittance</td>
<td>$\varepsilon_x$</td>
<td>18</td>
<td>24</td>
<td>3.2</td>
<td>4.6</td>
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<tr>
<td>emittance ratio</td>
<td>$\kappa$</td>
<td>0.88</td>
<td>0.66</td>
<td>0.37</td>
<td>0.40</td>
</tr>
<tr>
<td>beta-function at IP</td>
<td>$\beta_x*/\beta_y*$</td>
<td>1200/5.9</td>
<td>32/0.27</td>
<td>25/0.30</td>
<td>mm</td>
</tr>
<tr>
<td>beam currents</td>
<td>$I_b$</td>
<td>1.64</td>
<td>1.19</td>
<td>3.6</td>
<td>2.6</td>
</tr>
<tr>
<td>beam-beam parameter</td>
<td>$\xi_y$</td>
<td>0.129</td>
<td>0.09</td>
<td>0.0881</td>
<td>0.0807</td>
</tr>
<tr>
<td>beam size at IP</td>
<td>$\sigma_x*/\sigma_y*$</td>
<td>100/2</td>
<td>10/0.059</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Luminosity</td>
<td>$\mathcal{L}$</td>
<td>2.1$x10$</td>
<td></td>
<td></td>
<td>$8\times10^{35}$</td>
</tr>
</tbody>
</table>
High-Luminosity Asymmetric B Factory

- Target luminosity is \( \mathcal{L} = 8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1} \) (x40 w.r.t. BELLE)

- Achievable in the *nano-beam scheme* (P. Raimondi for SuperB)
  - double beam currents
  - squeeze beams @ IP

- **reduced CM boost**
  - reduced vertex separation, \( \Delta t \) resolution
  - increased detector hermeticity

### Table: Parameter Comparison

<table>
<thead>
<tr>
<th></th>
<th>LER</th>
<th>HER</th>
</tr>
</thead>
<tbody>
<tr>
<td>beam energy ( E_b )</td>
<td>3.5</td>
<td>8</td>
</tr>
<tr>
<td>CM boost ( \beta \gamma )</td>
<td>0.425</td>
<td>0.28</td>
</tr>
<tr>
<td>horizontal lifetime</td>
<td>24</td>
<td>32</td>
</tr>
<tr>
<td>horizontal divergence</td>
<td>0.66</td>
<td>0.37</td>
</tr>
<tr>
<td>beam lifetime</td>
<td>5.9</td>
<td>25</td>
</tr>
<tr>
<td>beam radius</td>
<td>1.19</td>
<td>3.6</td>
</tr>
<tr>
<td>beam energy spread</td>
<td>0.90</td>
<td>0.0881</td>
</tr>
<tr>
<td>beam energy spread</td>
<td>0.081</td>
<td>0.0807</td>
</tr>
<tr>
<td>x40 luminosity</td>
<td>8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}</td>
<td></td>
</tr>
</tbody>
</table>

higher background rates (~10-20x)
- detectors occupancy, radiation damage, fake hits, pile-up noise in the calorimeter
- higher event rate
  - higher trigger rate, DAQ, computing
- **x40 produced signal events**
Belle II Detector

- All sub-detectors are upgraded from Belle II:
  - Except for ECL crystals and a part of Barrel KLM
- Improved IP and secondary vertex resolution
- Better K/π separation and flavor tagging
- Higher Ks, π0 and slow pion reconstruction efficiency
Belle II Collaboration

800+ colleagues, 25 countries/regions
Revamped collider hunts for cracks in the fundamental theory of physics

Experiment smashes electrons into positrons to search for unseen particles and problems with overarching physics framework.

Elizabeth Gibney
Transitions to Operations

Photo credit: M. Friedl
**Phase I**: commissioning of the main ring; installation of outer detectors; vacuum scrubbing and beam bkg. studies

**Phase 2**: start of the collisions, detector commissioning without vertex detector; first physics runs on Y(4S) and Y(6S) (~20 ± 20 fb⁻¹) [now- July 2018]

**Phase 3**: full detector operation in the end of 2018
15.01.2018: MILESTONE!
Superconductive magnet systems installed
14.02.2018: Phase-II Has Started
A hadronic event recorded at h. 00:38, 26.04.2018 – first collision confirmation

IP size: 400 μm in X, 4 μm in Y
Peak Luminosity: 7.9 \times 10^{31} \text{ cm}^{-2}\text{s}^{-1}
SuperKEKB operation status

HER Luminosity: 7.046 (now) 12.295 (peak in 24 H @ 1.5.43) \(10^{27}/\text{cm}^2/\text{sec}\)

Integ. Lumi.: 0.12 (Fill) 0.12 (Day) 0.12 (24 H) \([\text{pb}]\)

Beam Current [A]

LHR

5/27/2018

Accelerator study

Beam-Beam deflections were observed: 2018/04/25
The first collision was observed: 2018/04/26
Phase 2.1.1 collision optics: 2018/05/22

5/27/2018 22:55 IST

Luminosity \([10^{32}]\)

Pressure [Pa]

 lifetime [min]
First Preliminary Study with Data (5 pb$^{-1}$)

**ππ** invariant mass

\[ \int L = -5 \text{ pb}^{-1} \]

*Belle II* 2018 Preliminary

First bumps observed!

\[ 1.845 < M(K\pi) < 1.885 \text{ (GeV/c}^2\text{)} \]

\[ D^* \rightarrow D^0(\rightarrow K^- \pi^+) \pi \]

**YY** invariant mass

\[ \int L \ dt = -5 \text{ pb}^{-1} \]

*Belle II* 2018 (Preliminary)

\[ E_\gamma > 0.15 \text{ GeV} \]

\[ 0.144 < \Delta M < 0.146 \text{ (GeV/c}^2\text{)} \]

Calibrations at a very early stage, no PID cuts applied
Status of Belle II Physics Book

- Belle II physics book (>630 pages), to be printed by PTEP very soon
- The contents include Belle II detector, simulation, reconstruction, analysis software, B decays, CKM angles, charm, quarkonium(-like), \( \tau \), new physics, …
- Some golden channels are given with Belle II MC simulations, theoretical discussions, sensitivity and systematic estimates

### Table: MC signal and background estimates for \( \tau \to \gamma\mu \)

<table>
<thead>
<tr>
<th>Mode</th>
<th>Eff.(%)</th>
<th>( N_{BG}^{\exp} )</th>
<th>UL (10^{-8})</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \mu\eta(\to \gamma\gamma) )</td>
<td>8.2</td>
<td>0.63 ± 0.37</td>
<td>3.6</td>
</tr>
<tr>
<td>( \epsilon\eta(\to \gamma\gamma) )</td>
<td>7.0</td>
<td>0.66 ± 0.38</td>
<td>8.2</td>
</tr>
<tr>
<td>( \mu\eta'(\to \pi\pi\eta) )</td>
<td>6.9</td>
<td>0.23 ± 0.23</td>
<td>8.6</td>
</tr>
<tr>
<td>( \epsilon\eta'(\to \pi\pi\eta) )</td>
<td>6.3</td>
<td>0.69 ± 0.40</td>
<td>8.1</td>
</tr>
<tr>
<td>( \mu\eta(\text{comb.}) )</td>
<td>2.3</td>
<td></td>
<td>2.3</td>
</tr>
<tr>
<td>( \epsilon\eta(\text{comb.}) )</td>
<td>4.4</td>
<td></td>
<td>4.4</td>
</tr>
<tr>
<td>( \mu\eta'(\text{comb.}) )</td>
<td>8.1</td>
<td>0.00^{+0.16}_{-0.00}</td>
<td>10.0</td>
</tr>
<tr>
<td>( \epsilon\eta'(\text{comb.}) )</td>
<td>7.3</td>
<td>0.63 ± 0.45</td>
<td>9.4</td>
</tr>
<tr>
<td>( \mu\eta'(\to \gamma\rho^0) )</td>
<td>6.2</td>
<td>0.59 ± 0.41</td>
<td>6.6</td>
</tr>
<tr>
<td>( \epsilon\eta'(\to \gamma\rho^0) )</td>
<td>7.5</td>
<td>0.29 ± 0.29</td>
<td>6.8</td>
</tr>
<tr>
<td>( \mu\pi^0 )</td>
<td>4.2</td>
<td>0.64 ± 0.32</td>
<td>2.7</td>
</tr>
<tr>
<td>( \epsilon\pi^0 )</td>
<td>4.7</td>
<td>0.89 ± 0.40</td>
<td>2.2</td>
</tr>
</tbody>
</table>
Prospects of $\tau$ decays at Belle II
Precise studies of $\tau$ at $B$ factories

Michel parameters in $\tau \rightarrow \ell \nu \nu (\rho, \eta, \xi, \delta)$ at Belle: arXiv:1409.4969

Study of the radiative leptonic decays $\tau \rightarrow \ell \nu \nu \gamma$:

$\textbf{BABAR}$: Measurement of $\mathcal{B}(\tau \rightarrow \ell \nu \nu \gamma)$; PRD 91, 051103(R) (2015)

$\textbf{Belle}$ (prelim.): $\bar{\eta} = -1.3 \pm 1.5 \pm 0.8$, $\xi \kappa = 0.5 \pm 0.4 \pm 0.2$; arXiv:1609.08280

Lepton universality with $\tau \rightarrow \ell \nu \nu$ and $\tau \rightarrow h \nu$ (h=\(\pi,K\)) at $\textbf{BABAR}$:

\[
\left( \frac{g_{\mu}}{g_{e}} \right)_{\tau} = 1.0036 \pm 0.0020, \left( \frac{g_{\tau}}{g_{\mu}} \right)_{h} = 0.9850 \pm 0.0054; \text{PRL 105, 051602 (2010)}
\]

Tau lifetime:

$\textbf{Belle}$: $\tau_{\tau} = (290.17 \pm 0.53 \text{(stat)} \pm 0.33 \text{(syst)}) \text{ fs}; \text{PRL 112, 031801 (2014)}$

$\textbf{BABAR}$ (prelim.): $\tau_{\tau} = (289.40 \pm 0.91 \text{(stat)} \pm 0.90 \text{(syst)}) \text{ fs}; \text{Nucl. Phys. B 144, 105 (2005)}$

Tau mass:

$\textbf{Belle}$: $m_{\tau} = (1776.61 \pm 0.13 \text{(stat)} \pm 0.35 \text{(syst)}) \text{ MeV}/c^2; \text{PRL 99, 011801 (2007)}$

$\textbf{BABAR}$: $m_{\tau} = (1776.68 \pm 0.12 \text{(stat)} \pm 0.41 \text{(syst)}) \text{ MeV}/c^2; \text{PRD 80, 092005 (2009)}$

Accuracy comparable with the most precision measurements done by $\text{BES}$ and $\text{KEDR}$ at the $\tau^+ \tau^-$ production threshold.

Tau electric dipole moment (EDM):

$\textbf{Belle}$: $\Re(d_{\tau}) = (1.15 \pm 1.70) \times 10^{-17} \text{ e\cdot cm}$, $\Im(d_{\tau}) = (-0.83 \pm 0.86) \times 10^{-17} \text{ e\cdot cm}$; PLB 551, 16 (2003) ($\int L dt = 29.5 \text{ fb}^{-1}$) We are working on EDM with full Belle statistics

Hadronic contribution to $a_{\mu}$ ($\tau^- \rightarrow \pi^- \pi^0 \nu_\tau$):

$\textbf{Belle}$: $a_{\mu}^{\pi\pi} = (523.5 \pm 1.1 \text{(stat)} \pm 3.7 \text{(syst)}) \times 10^{-10}; \text{PRD 78, 072006 (2008)}$
Lepton-flavor-violating (LFV) decays of $\tau$

<table>
<thead>
<tr>
<th>Model</th>
<th>Reference</th>
<th>$\tau \to \mu \gamma$</th>
<th>$\tau \to \mu \mu \mu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM+ $\nu$ oscillations</td>
<td>EPJ C8 (1999) 513</td>
<td>$10^{-40}$</td>
<td>$10^{-14}$</td>
</tr>
<tr>
<td>SM+ heavy $\nu_R$</td>
<td>PRD 66 (2002) 034008</td>
<td>$10^{-9}$</td>
<td>$10^{-10}$</td>
</tr>
<tr>
<td>Non-universal $Z'$</td>
<td>PLB 547 (2002) 252</td>
<td>$10^{-9}$</td>
<td>$10^{-8}$</td>
</tr>
<tr>
<td>SUSY SO(10)</td>
<td>PRD 68 (2003) 033012</td>
<td>$10^{-6}$</td>
<td>$10^{-10}$</td>
</tr>
<tr>
<td>mSUGRA+seesaw</td>
<td>PRD 66 (2002) 115013</td>
<td>$10^{-7}$</td>
<td>$10^{-9}$</td>
</tr>
<tr>
<td>SUSY Higgs</td>
<td>PLB 566 (2003) 217</td>
<td>$10^{-10}$</td>
<td>$10^{-7}$</td>
</tr>
</tbody>
</table>

- Probability of LFV decays of charged leptons is extremely small in the Standard Model, \[ B(\tau \to l\gamma) = \frac{3\alpha}{32\pi} \left| \sum_i U_{\tau i}^* U_{\mu i} \frac{\Delta^2_{3i}}{m_W^2} \right|^2 \leq 10^{-53} \sim 10^{-49} \]

- Many models beyond the SM predict LFV decays with the branching fractions up to $\lesssim 10^{-8}$. As a result, observation of LFV is a clear signature of New Physics (NP).

- $\tau$ lepton is an excellent laboratory to search for the LFV decays due to the enhanced couplings to the new particles as well as the large number of LFV decay modes.

- Study of the different $\tau$ LFV decay modes allows us to test various NP models.
τ LFV in NP beyond SM

Ratios of τ LFV decay’s BF’s allow one to discriminate between new physics models

<table>
<thead>
<tr>
<th></th>
<th>SUSY+GUT (SUSY+Seesaw)</th>
<th>Higgs mediated</th>
<th>Little Higgs</th>
<th>non-universal Z'</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{B(\tau \to \mu \mu \mu)}{B(\tau \to \mu \gamma)}$</td>
<td>$\sim 2 \times 10^{-3}$</td>
<td>0.06 - 0.1</td>
<td>0.4 - 2.3</td>
<td>$\sim 16$</td>
</tr>
<tr>
<td>$\frac{B(\tau \to \mu e e)}{B(\tau \to \mu \gamma)}$</td>
<td>$\sim 1 \times 10^{-2}$</td>
<td>$\sim 1 \times 10^{-2}$</td>
<td>0.3 - 1.6</td>
<td>$\sim 16$</td>
</tr>
<tr>
<td>$B(\tau \to \mu \gamma)_{\text{max}}$</td>
<td>$&lt; 10^{-7}$</td>
<td>$&lt; 10^{-10}$</td>
<td>$&lt; 10^{-10}$</td>
<td>$&lt; 10^{-9}$</td>
</tr>
</tbody>
</table>

JHEP 0705, 013 (2007); PLB 547, 252 (2002)

∴ Good to measure LFV in as many modes as possible!
Past searches for $\tau \to \gamma \mu$ at Belle

- Blinding box approach with BG evaluated outside the signal region
- Observables space: $\Delta E = E_{\text{CM}}^{(\mu+\gamma)} - E_{\text{beam}}/2$ (expected $\Delta E = 0$)
  - Signal-side $m_{\text{inv}}$ (expected $m_{\text{inv}} = m_\tau = 1.777$ GeV/c$^2$)
- Signal regions after BG rejection cuts — data (points) and signal MC (shaded):

\[ \tau^+ \rightarrow \mu^+ \gamma \]

\[ \Delta E (\text{GeV}) \]

\[ M_{\text{inv}} (\text{GeV}/c^2) \]

- $B(\tau^- \rightarrow \mu^- \gamma) < 4.5 \times 10^{-8}$
- $B(\tau^- \rightarrow e^- \gamma) < 12.0 \times 10^{-8}$ @ 90%CL
- $B(\tau^- \rightarrow \mu^- \gamma) < 4.4 \times 10^{-8}$
- $B(\tau^- \rightarrow e^- \gamma) < 3.3 \times 10^{-8}$

$\tau \to \gamma \mu$ at Belle II

sensitivity study using Belle II MC incl. beam background simulation

- for sensitivity comparison with Belle (with $\int L \, dt = 1 \text{ ab}^{-1}$)

Background:

- $\tau \to \mu \nu \nu$
- $\tau \to e \nu \nu$
- $\tau \to \pi \nu$
- $\tau \to e e / \mu \mu$ ($\gamma$)
- $ee \to$ hadronic

Background rejection by

- event shape variables — thrust, Fox-Wolfram moments, momentum flow distributions (“CLEO cones”), etc.

Signal extraction by $(\Delta E, M_{\text{inv}})$

- rotating $(M_{\text{inv}}, \Delta E)$ to minimize correlation
$\tau \rightarrow \gamma \mu$ sensitivity at Belle II

<table>
<thead>
<tr>
<th></th>
<th>Belle (535 fb$^{-1}$)</th>
<th>Belle II (1 ab$^{-1}$)</th>
<th>Belle II (50 ab$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mathcal{L}$ (cm$^2$/s)</td>
<td>2.11 x 10$^{34}$</td>
<td>80 x 10$^{34}$</td>
<td>5.5 x 10$^{-10}$</td>
</tr>
<tr>
<td>$\varepsilon_{\text{signal}}$</td>
<td>5.09%</td>
<td>4.59%</td>
<td></td>
</tr>
<tr>
<td>$n_{BG}$</td>
<td>10</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>$B_{90}(\tau \rightarrow \mu \gamma)$</td>
<td>4.5 x 10$^{-8}$</td>
<td>2.7 x 10$^{-8}$</td>
<td></td>
</tr>
</tbody>
</table>

First $\tau$ LFV sensitivity study at Belle II

- even with much higher beam background, the sensitivity is comparable to that of Belle (scaled by luminosity)
- signal region is background-free
τ LFV summary & prospects

HFAG summary plot for τ LFV decays, overlaid with Belle II extrapolation to 50 ab⁻¹ assuming zero background
CPV in hadronic $\tau$ decays

- CPV has never been observed in lepton decays; SM ($A_{CP} \leq 10^{-12}$)
- Observation of large CPV would be clear signal of NP, for examples, MSSM[IHEP12,021;RMP80,577], multi-Higgs-doublet-models [PRL37,657;NPB426,355]
- $\tau \rightarrow 2\pi\nu$ [PRD50,4544], $K\pi\nu$ [PLB398,407], $3\pi\nu$ [PRD52,1614], $K\pi\pi\nu, KK\pi\nu$ [Z. Phys.G62,413; PRD78, 113008; PRD91, 073006] have been suggested to do CPV measurements.
CPV in hadronic $\tau$ decays

Two ways to measure CPV in hadronic $\tau$ decays

I: Direct measure positive and negatively charged tau lepton decays

$$\tau^- \rightarrow \pi^- K_S (\geq 0\pi^0) \nu_\tau$$ : BaBar (PRD85, 031102(2012); 476 fb$^{-1}$)

$$A_{cp} = \frac{\Gamma(\tau^+ \rightarrow \pi^+ K_S (\geq 0\pi^0) \bar{\nu}_\tau) - \Gamma(\tau^- \rightarrow \pi^- K_S (\geq 0\pi^0) \bar{\nu}_\tau)}{\Gamma(\tau^+ \rightarrow \pi^+ K_S (\geq 0\pi^0) \bar{\nu}_\tau) + \Gamma(\tau^- \rightarrow \pi^- K_S (\geq 0\pi^0) \bar{\nu}_\tau)} = (-0.36 \pm 0.23 \pm 0.11)\%$$

2.8$\sigma$ deviation from the SM expectation: $A_{CP(SM)} = (+0.36 \pm 0.01)\%$
CPV in hadronic $\tau$ decays

II: CPV in $\tau^- \rightarrow \pi^- K S \nu_\tau$ at Belle (PRL107, 131801(2011); 699 fb$^{-1}$)
Angular distributions were analyzed, $A_{CP}(W = M_{K_S\pi})$ was measured

$\eta_S$ is the dimensionless complex coupling constant

$$A_{i CP} = \frac{\int Q_{2,i}^2 \cos \beta \cos \psi (d\Gamma_\tau^- - d\Gamma_\tau^+) d\omega}{\frac{1}{2} \int Q_{2,i}^2 (d\Gamma_\tau^- + d\Gamma_\tau^+) d\omega}$$

$$\approx \langle \cos \beta \cos \psi \rangle_{\tau^-}^{i} - \langle \cos \beta \cos \psi \rangle_{\tau^+}^{i}, \quad d\omega = dQ^2 d\cos \theta d\cos \beta$$

With 50 ab$^{-1}$ data at Belle II, we expect 70 times improvement, i.e., $|A_{CP}| < (0.5 - 3.8) \times 10^{-4}$, at 90% C.L. assuming the central value $A_{CP} = 0$.
Prospects of $B$ decays at Belle II
Time Dependent CP Violation

- Flagship measurements of the B-factories: access the weak phase of the CKM Matrix by exploiting the interference between mixing and decay:

\[ \Delta z = \beta \gamma c \Delta t \]
\[ \Delta t = t_{CP} - t_{tag} \]

All aspects of the experiment crucially important:
- tracking efficiency;
- neutrals reconstruction;
- vertexing;
- PID;
- B Flavor Tagging;
- background rejection;
- ...

- Significant improvements over the previous generation of experiments:
  - \( \Delta t \) resolution \( \sim 0.77 \) ps (30% to a factor 2 better compared to Belle);
  - effective flavor tagging efficiency \( \sim 35.8\% \) (was 30.1% at Belle).
Time Dependent CP Violation

- The measurement of $\sin 2\phi_1$ from $B \rightarrow cc K^0$ with the full dataset will be dominated by systematic uncertainties:

<table>
<thead>
<tr>
<th>Mode</th>
<th>Belle</th>
<th>Belle II (50 ab$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>$0.667 \pm 0.023 \pm 0.012$</td>
<td>$x.xxx \pm 0.0027 \pm 0.0044$</td>
</tr>
<tr>
<td>A</td>
<td>$0.006 \pm 0.016 \pm 0.012$</td>
<td>$x.xxx \pm 0.0033 \pm 0.0037$</td>
</tr>
</tbody>
</table>

(PRL 108 (2012), 171802)

- Most gluonic penguin dominated modes will be limited by statistical uncertainties.

These modes are theoretically clean, and can be used for precise tests for non-SM contributions.
Belle’s legacy on EWP

- First observation of $B \to K\ell^+\ell^-$  
  PRL 88, 021801 (2002)
- First observation of $B \to K^*\ell^+\ell^-$  
  PRL 91, 261601 (2003)
- First observation of $B \to X_s\ell^+\ell^-$  
  PRL 90, 021801 (2003)
- First measurement of $A_{FB}$ of $B \to K^*\ell^+\ell^-$  
  PRL 96, 251801 (2006)
- First observations of several radiative modes, $\phi K \gamma$, $K_1 \gamma$, etc.
- First observation of $B \to (\rho, \omega)\gamma$  
  PRL 96, 221601 (2006)
- Most precise measurement of $B \to X_s\gamma$  
  covering the widest $E_\gamma$ range  
  PRL 103, 241801 (2009)
- and many more published results
Electroweak Penguins

• Several tensions at the 2-3σ level

Projection of uncertainties at Belle II for $P_5'$

<table>
<thead>
<tr>
<th>$q^2$ (GeV$^2$/c$^4$)</th>
<th>Belle</th>
<th>Belle II</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 – 4</td>
<td>0.416</td>
<td>0.059</td>
</tr>
<tr>
<td>4 – 8</td>
<td>0.277</td>
<td>0.040</td>
</tr>
<tr>
<td>10.09 – 12</td>
<td>0.344</td>
<td>0.049</td>
</tr>
<tr>
<td>14.18 – 19</td>
<td>0.248</td>
<td>0.033</td>
</tr>
</tbody>
</table>

• Lepton Flavor Universality violation in $B^+ \rightarrow K^+ l^+ l^-$?

$$R_K = \frac{\int_{q^2_{\text{min}}}^{q^2_{\text{max}}} dq^2 \frac{d\Gamma[B^+ \rightarrow K^+ \mu^+ \mu^-]}{dq^2}}{\int_{q^2_{\text{min}}}^{q^2_{\text{max}}} dq^2 \frac{d\Gamma[B^+ \rightarrow K^+ e^+ e^-]}{dq^2}} \approx 1$$

• LHCb will have the edge on many of these decays, but confirmation from Belle II will be crucial.
R(K), R(K*), R(Xs) at Belle II

- The errors reach to 0.04 for all K, K* and Xs modes in Belle II.
- Errors are still statistically limited (systematic error ~ 0.4%)

- Belle II should be able to **claim** the R(K(*)) anomaly with a significance of 5σ, if it is indeed due to new physics.
- However electron mode is challenging at LHCb, especially for high q².
Search for NP in $B^+ \rightarrow \tau^+ \nu_\tau$

- Branching ratio depends strongly on the mass of the lepton due to helicity suppression. Thus $B^+ \rightarrow \tau^+ \nu_\tau$ is expected to have the largest leptonic branching fraction.
- NP could significantly suppress or enhance the branching ratio i.e. via exchange a charged Higgs boson from supersymmetry or from two-Higgs doublet models (2HDM).
- In the absence of NP, this channel provides a direct determination of the $B$ decay constant $f_B$ and the CKM matrix $|V_{ub}|$.

\[
\mathcal{B}(B^+ \rightarrow \tau^+ \nu_\tau)_{SM} = \frac{G_F m_B m_\tau^2}{8\pi} \left(1 - \frac{m_\tau^2}{m_R^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B
\]

- Hadronic tagging
- dominate backgrounds: $B^{-} \rightarrow D^{(*)0} \ell^{-} \bar{\nu}_\ell$
  
\[
[0.72^{+0.27}_{-0.25}(\text{stat}) \pm 0.11(\text{syst})] \times 10^{-4}
\]

- Semi-leptonic tagging (agree with Had. tag and SM)
  
\[
\mathcal{B}(B^+ \rightarrow \tau^+ \nu_\tau) = [1.25 \pm 0.28(\text{stat}) \pm 0.27(\text{syst})] \times 10^{-4}
\]
$B^+ \rightarrow \tau^+ \nu_\tau$ prospect at Belle II

- Analysis on Belle II full simulation using hadronic $B$ reconstruction.
- Signal yields extracted from fit to extra neutral energy.
- The extra energy resolution at Belle II is better than Belle despite the increased beam background.

### Comparison with Belle hadronic tag. 1 ab$^{-1}$ equivalent statistics

<table>
<thead>
<tr>
<th>$E_{ECL}$</th>
<th>$&lt; 0.25$ GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td># background events</td>
<td>1348</td>
</tr>
<tr>
<td># signal events</td>
<td>136</td>
</tr>
<tr>
<td>signal efficiency ($%$)</td>
<td>1.6</td>
</tr>
<tr>
<td># background events</td>
<td>365</td>
</tr>
<tr>
<td># signal events</td>
<td>60</td>
</tr>
<tr>
<td>signal efficiency ($%$)</td>
<td>0.7</td>
</tr>
</tbody>
</table>

### Extrapolation at full Belle II statistics

<table>
<thead>
<tr>
<th>hadronic tag</th>
<th>Integrated Luminosity (ab$^{-1}$)</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>statistical uncertainty (%)</td>
<td>4.1</td>
</tr>
<tr>
<td></td>
<td>systematic uncertainty (%)</td>
<td>4.6</td>
</tr>
<tr>
<td></td>
<td>total uncertainty (%)</td>
<td>6.2</td>
</tr>
<tr>
<td>semileptonic tag</td>
<td>statistical uncertainty (%)</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>systematic uncertainty (%)</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>total uncertainty (%)</td>
<td>5.3</td>
</tr>
</tbody>
</table>
Search NP in $B \rightarrow D^{(*)} \tau^+ \nu_\tau$

- In the Standard Model (SM), the only difference between $B \rightarrow D^{(*)} \tau^+ \nu_\tau$ and $B \rightarrow D^{(*)} \mu^+ \nu_\mu$ is the mass of the lepton.
- The ratio of them is sensitive to additional amplitudes, i.e. involving an intermediate charged Higgs boson.
- NP: type-II-2HDM (charged Higgs boson appears), Leptoquarks(LQ) model...
- NP could affect this decay topology in two ways:
  - Branching fraction
  - $\tau$ polarization
$\mathcal{R}(D^{(*)})$ in $B \rightarrow D^{(*)} \tau^+\nu_\tau$

Test for lepton universality using the ratio typically:

\[ \mathcal{R}(D^{(*)}) = \frac{\mathcal{B}(\bar{B} \rightarrow D^{(*)} \tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \rightarrow D^{(*)} \ell^-\bar{\nu}_\ell)} \quad (\ell = e, \mu). \]

SM: $\mathcal{R}(D) = 0.300 \pm 0.008$ Phys. Rev. D 92, 034506 (2015)

$\mathcal{R}(D^*) = 0.252 \pm 0.003$ Phys. Rev. D 85, 094025 (2012)

- Current world average for $\mathcal{R}(D^{(*)})$ is in $\sim 4.1\sigma$ tension with SM!
\( \tau \) Polarization in \( B \to D^{(*)}\tau^+\nu_{\tau} \)

First measurement of the tau polarization in this decay.
First use tau had. decays in \( B \to D^{(*)}\tau^+\nu_{\tau} \)
\( \tau^- \to \pi^-\nu_{\tau} \), \( \tau^- \to \rho^-\nu_{\tau} \)

Belle PRL 118, 211801 (2017) had. tag

\[
P_{\tau}(D^*) = \frac{\Gamma^+ - \Gamma^-}{\Gamma^+ + \Gamma^-}
\] for right- (left-)handed \( \tau \)

\begin{align*}
R(D^*) &= 0.270 \pm 0.035 \text{(stat.)} ^{+0.028}_{-0.025} \text{ (syst.)} \\
\mathcal{P}_{\tau}(D^*) &= -0.38 \pm 0.51 \text{(stat.)} ^{+0.21}_{-0.16} \text{ (syst.)}
\end{align*}

Compatibility with the SM.

\[ P_{\tau}(D^*)_{\text{SM}} = -0.497 \pm 0.013 \text{ Phys. Rev. D 87, 034028 (2013)} \]
$B \rightarrow D^{(*)} \tau^+ \nu_{\tau}$ prospect at Belle II

- Current measurements are statistically limited, dominant systematic uncertainties from
  - limited signal MC samples $\rightarrow$ larger at Belle II
  - limited knowledge of dominant bkg (involving soft pions) $\rightarrow$ dedicated measurement with large data samples feasible at Belle II
- With higher statistics, study polarization and $q^2$ distributions, essential to distinguish NP.

### Uncertainties at Belle II

<table>
<thead>
<tr>
<th></th>
<th>5 ab$^{-1}$</th>
<th>50 ab$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_D$</td>
<td>$(\pm 6.0 \pm 3.9)%$</td>
<td>$(\pm 2.0 \pm 2.5)%$</td>
</tr>
<tr>
<td>$R_{D^*}$</td>
<td>$(\pm 3.0 \pm 2.5)%$</td>
<td>$(\pm 1.0 \pm 2.0)%$</td>
</tr>
<tr>
<td>$P_{\tau}(D^*)$</td>
<td>$\pm 0.18 \pm 0.08$</td>
<td>$\pm 0.06 \pm 0.04$</td>
</tr>
</tbody>
</table>

the first and the second values are the expected statistical and systematic errors.
$B$-factories have provided unprecedented information on the flavor dynamics in SM: CPV in $B/D$ decays, evidence in $D\bar{D}$ mixing, XYZ states, (semi-)leptonic $B$ decays, …

$B$-factory is also a $\tau$-factory experiment. With $\sim 1$ billion $\tau^+\tau^-$ sample, many precise measurements and most stringent upper limits in $\tau$ LFV/LNV/BNV are obtained.

Belle II will start full physics run in the end of 2018, reach 50 ab$^{-1}$ by 2023-2024, which will provide greater sensitivity and complimentary approach to LHC in flavor physics area: CKM angles, CPV in $B$ and charm decays, NP searches at the loop level, …

With $\sim 50$ billion $\tau^+\tau^-$ events expected at Belle II, most searches and measurements in $\tau$ decays will be greatly improved.

Belle II physics book (to be published in PTEP):
https://confluence.desy.de/display/BII/B2TiP+ReportStatus
Michel parameters

In the SM charged weak interaction is described by the exchange of $W^\pm$ with a pure vector coupling to only left-handed fermions ("V-A" Lorentz structure). Deviations from "V-A" indicate New Physics. $\tau^- \rightarrow \ell^- \bar{\nu}_\ell \nu_\tau$ ($\ell = e, \mu$) decays provide clean laboratory to probe electroweak couplings. The most general, Lorentz invariant four-lepton interaction matrix element:

$$\mathcal{M} = \frac{4G}{\sqrt{2}} \sum_{N=S,V,T} \sum_{i,j=L,R} g_{ij}^N \left[ \bar{u}_j(l^-) \Gamma^N v_n(\bar{\nu}_l) \right] \left[ \bar{u}_m(\nu_\tau) \Gamma_N u_j(\tau^-) \right],$$

$$\Gamma^S = 1, \quad \Gamma^V = \gamma^\mu, \quad \Gamma^T = \frac{i}{2\sqrt{2}}(\gamma^\mu \gamma^\nu - \gamma^\nu \gamma^\mu)$$

Ten couplings $g_{ij}^N$, in the SM the only non-zero constant is $g_{LL}^V = 1$

Four bilinear combinations of $g_{ij}^N$, which are called as Michel parameters (MP): $\rho, \eta, \xi$ and $\delta$ appear in the energy spectrum of the outgoing lepton:

$$\frac{d\Gamma(\tau^\pm)}{d\Omega dx} = \frac{4G_F^2 M_\tau E_{\text{max}}^4}{(2\pi)^4} \sqrt{x^2 - x_0^2} \left( x(1-x) + \frac{2}{9} \rho(4x^2 - 3x - x_0^2) + \eta x_0(1-x) \right)$$

$$\mp \frac{1}{3} P_\tau \cos \theta_\ell \xi \sqrt{x^2 - x_0^2} \left[ 1 - x + \frac{2}{3} \delta(4x - 4 + \sqrt{1 - x_0^2}) \right], \quad x = \frac{E_\ell}{E_{\text{max}}}, \quad x_0 = \frac{m_\ell}{E_{\text{max}}}$$

In the SM: $\rho = \frac{3}{4}, \eta = 0, \xi = 1, \delta = \frac{3}{4}$
SVD ladder mount

• Jan 2018: Mount of the +X half shell was successfully completed
First Measurements of Beam Backgrounds at SuperKEKB, submitted to NIMA, 101 pages

Final experiment/simulation

LER beam gas: $2.8^{+3.4}_{-2.3}$
LER Touschek: $1.4^{+1.8}_{-1.1}$
HER beam gas: $108^{+180}_{-64}$
HER Touschek: $4.8^{+8.2}_{-2.8}$

Phase 2 dedicated beam background detectors installed
- VX D Volume: FANGS, CLAWS, PLUME
- VX D dock space: TPCs, He-3 tubes
- On QCS: PIN diodes, scintillators

Next challenge: Phase 2 integration of DAQ and simulation

S. Vahsen, H. Nakayama et al
Phase III:

Milestone: Completion of +X clam-shell of the SVD on Jan 18, 2018
Higher energy run

- Design: original design maximum energy is 11.05 GeV at $\Upsilon(6S)$
- Possible higher energy run (11.5 GeV – 12 GeV)?
  - If any, higher energy run will be after several years running at $\Upsilon(4S) \sim \Upsilon(6S)$
  - **Present max $E_{\text{cm}}$ is 11.24 GeV**, limited by $e^-$ Linac and $e^+$ BT magnets
  - In order to inject the electron beam to HER at the required energy for 12 GeV operation, there must be huge reinforcement of Linac (replacement of S-band with C-band, $7.571 \rightarrow 8.6$ GeV)

11.24 GeV region: $\Lambda_b \bar{\Lambda}_b$ threshold

---

**Diagram**: Graph showing energy levels and limits for the electron beam and HER energy. Key points include:
- $\Upsilon(4S)$ and $\Upsilon(6S)$ references
- Present attainable $E_{\text{cm}}$ max
- Energy levels: 11.05 GeV, 11.24 GeV, 11.6 GeV, 11.8 GeV, 12 GeV
- QC1E(HER) 90% quench limit
- QC1P(LER) 90%
- Power supply of LER main dipoles
- 4.364 GeV @ 860A

---

Additional note:
- **e.g. [arXiv:1211.0103]**
- On-going discussion with SuperKEKB people about beam energy measurement using backscattered photons produced by laser radiation scattered head-on the beams
Electroweak Penguins

- Very suppressed in the SM (BF \(\sim 10^{-6}\));
- Many observables and often very precise predictions from theory;

Sensitive to the:
- \(C_7\): electromagnetic penguin
- \(C_9\): vector electroweak
- \(C_{10}\): axial-vector electroweak

Wilson Coefficients

![Graphs and diagrams illustrating electroweak penguins and their observables.](image-url)
Electroweak Penguins: $P'_5$

- Angular analysis of $B^0 \rightarrow K^{*0}\mu^+\mu^-$;
- Many observables investigated, can cancel the leading uncertainty on hadronic form factor by defining “optimised” observables:
- Interesting discrepancy is observed in $P'_5$;

(full definitions of observables in backup)

- Global fit to complete set of observables gives a $3.4\sigma$ tension with SM: New Physics or hadronic effects larger than expected?
- While the experiments improve the precision, input from theory is essential.
Electroweak Penguins: LUV?

- Tests of Lepton Universality in $b \rightarrow s l^+l^-$ decays can reveal the presence of Higgs-like particles;
- LHCb measured the ratio $R_K$ in $B^+ \rightarrow K^+l^+l^-$: 
  \[ R_K = \frac{\int_{q^2_{\text{min}}}^{q^2_{\text{max}}} \frac{d\Gamma[B^+ \rightarrow K^+\mu^+\mu^-]}{dq^2} \, dq^2}{\int_{q^2_{\text{min}}}^{q^2_{\text{max}}} \frac{d\Gamma[B^+ \rightarrow K^+e^+e^-]}{dq^2} \, dq^2} \approx 1 \text{ (modulo tiny corrections)} \]
- Challenging analysis, need to correct for Bremstrahlung;
- In $1 < q^2 < 6$ GeV$^2$:
  \[ R_K = 0.745^{+0.090}_{-0.074}\,\text{(stat)} \pm 0.036\,\text{(syst)} \]
- 2.6$\sigma$ tension wrt expectation: this needs confirmation!

LHCb Collaboration, 
PRL 113, 151601 (2014)
Electroweak Penguins: Outlook

- Quite a few channels where LHCb will improve a lot in the next couple years:
  - $B \rightarrow \pi l^+ l^-$;
  - $B_s \rightarrow \phi l^+ l^-$;
  - $\Lambda_b \rightarrow \Lambda l^+ l^-$;
  - ...

  } Keep refining precision on differential BF's, CP asymmetries, angular observables, Lepton Universality...

- ... and quite a few more where we need to wait for Belle II:
  - $B \rightarrow K^{(*)} \tau^+ \tau^-$; current limit ~2 orders of magnitude above predictions
  - $B \rightarrow K^{(*)} \nu \bar{\nu}$; might see a signal with full dataset
  - $B \rightarrow \gamma \gamma$; but it is crucial to control the machine backgrounds
  - (semi-)inclusive $b \rightarrow d/s \gamma$
  - Time dependent CPV in $B^0 \rightarrow K_S \pi^0 \gamma$, $B^0 \rightarrow \rho^0 \gamma$
  - ...

...
Electroweak Penguins

- Definitions of main observables:

\[
\frac{d^4 \Gamma[\bar{B}^0 \to \bar{K}^{*0} \mu^+ \mu^-]}{dq^2 d\tilde{\Omega}} = \frac{9}{32\pi} \sum_i I_i(q^2) f_i(\tilde{\Omega})
\]

\[
\frac{d^4 \bar{\Gamma}[B^0 \to K^{*0} \mu^+ \mu^-]}{dq^2 d\tilde{\Omega}} = \frac{9}{32\pi} \sum_i \tilde{I}_i(q^2) f_i(\tilde{\Omega})
\]

\[S_i = (I_i + \tilde{I}_i) / \left( \frac{d\Gamma}{dq^2} + \frac{d\bar{\Gamma}}{dq^2} \right)\]

\[A_i = (I_i - \tilde{I}_i) / \left( \frac{d\Gamma}{dq^2} + \frac{d\bar{\Gamma}}{dq^2} \right)\]

I(q^2): q^2 dependent angular observables. They are expressed as a combination of 6 decay amplitudes (3 transversity states x 2 chirality states of the μμ system)

\[P_1 = \frac{2S_3}{(1 - F_L)} = A_T^{(2)}\]

\[P_2 = \frac{2 A_{FB}}{3 (1 - F_L)}\]

\[P_3 = \frac{-S_9}{(1 - F_L)}\]

\[P_{4,5,8} = \frac{S_{4,5,8}}{\sqrt{F_L(1 - F_L)}}\]

\[P_6' = \frac{S_7}{\sqrt{F_L(1 - F_L)}}\]
Electroweak Penguins: $A_{FB}$

$$A_{FB}(q^2_{min}, q^2_{max}) = \frac{1}{\int_{q^2_{min}}^{q^2_{max}} d\Gamma \int_{-1}^{1} d\cos \theta \sgn(\cos \theta) \frac{d^2\Gamma}{dq^2 d\cos \theta}}$$

$$\int_{q^2_{min}}^{q^2_{max}} d\Gamma \int_{-1}^{1} d\cos \theta \frac{d^2\Gamma}{dq^2 d\cos \theta}$$

$\theta$: angle between the $\ell^+$ ($\ell^-$) momentum and the $B$ ($B$) momentum in the $\ell^+\ell^-$ rest frame

$$\frac{1}{d\Gamma/dq^2} \frac{d^4\Gamma}{d\cos \theta_{\ell} d\cos \theta_K d\phi dq^2} = \frac{9}{32\pi} \left[ \frac{3}{4} (1 - F_L) \sin^2 \theta_K + F_L \cos^2 \theta_K \right.$$

$$+ \frac{1}{4} (1 - F_L) \sin^2 \theta_K \cos 2\theta_{\ell}$$

$$- F_L \cos^2 \theta_K \cos 2\theta_{\ell} + S_3 \sin^2 \theta_K \sin^2 \theta_{\ell} \cos 2\phi$$

$$+ S_4 \sin 2\theta_K \sin 2\theta_{\ell} \cos \phi + S_5 \sin 2\theta_K \sin \theta_{\ell} \sin \phi$$

$$+ S_6 \sin^2 \theta_K \cos \theta_{\ell} + S_7 \sin 2\theta_K \sin \theta_{\ell} \sin \phi$$

$$+ S_8 \sin 2\theta_K \sin 2\theta_{\ell} \sin \phi + S_9 \sin^2 \theta_K \sin^2 \theta_{\ell} \sin 2\phi \left. \right]$$

$$P'_5 = \frac{S_5}{\sqrt{F_L (1 - F_L)}}$$

$2.8$ and $3.0$ $\sigma$ from SM
Belle’s history of $B \rightarrow D^*\tau\nu$

- **First observation**
  \[ \mathcal{B}(B^0 \rightarrow D^{*-}\tau^+\nu_\tau) = (2.02^{+0.40}_{-0.37} \pm 0.37)\% \text{ with } 5.2\sigma \]
  
  *PRL 99, 191807 (2007)*

- **Updated w/ full-recon hadronic $B$-tag**
  \[ B \rightarrow D^*\tau\nu \text{ and } B \rightarrow D\tau\nu \]
  
  *PRD 92, 072014 (2015)*

- **Independent measurement w/ semileptonic $B$-tag**
  \[ B \rightarrow D^*\tau\nu \]
  
  *PRD 94, 072007 (2016)*

- **First measurement of $\tau$ polarization**
  \[ B \rightarrow D^*\tau\nu \]
  
  *PRL 118, 211801 (2017)*
  *PRD 97, 012004 (2018)*
$B \to K^{(*)}\nu\nu$: theoretical and experimental status

- Flavour changing neutral current, prohibited at tree level in the SM
  - NP contribution (from new mediators or sources of missing energy) may be comparable to SM ones
  - free of uncertain long-distant hadronic effects, theoretically clean

- Experimental searches from BaBar and Belle on both HAD and SL recoil$^{[knn2]}$
  - no signal evidence, UL less than 1 order of magnitude away from SM predictions for $K^*$ channels
B→K(*)υυ: robustness against machine background

- Analysis on Belle II Full simulation using hadronic B reconstruction using K^*+ →K\pi^0 to establish machine background impact
- Simple cut-and-count analysis, signal efficiency and bkg yield estimated in extra neutral energy signal region
- Nominal machine bkg (BGx1) and machine bkg-free (BGx0) simulated samples analysed
- Negligible impact of machine background both in terms of variables shape and signal significance

<table>
<thead>
<tr>
<th>1 ab^{-1} equivalent statistics</th>
<th>“BGx0”</th>
<th>“BGx1”</th>
</tr>
</thead>
<tbody>
<tr>
<td>N_{bkg}</td>
<td>6415 ± 80</td>
<td>3678 ± 61</td>
</tr>
<tr>
<td>ε (10^{-4})</td>
<td>10.3 ± 0.3</td>
<td>5.38 ± 0.23</td>
</tr>
<tr>
<td>N_{sig}/\sqrt{N_{bkg}}</td>
<td>0.16</td>
<td>0.15</td>
</tr>
<tr>
<td>UL (10^{-4})</td>
<td>2.6</td>
<td>3.8</td>
</tr>
</tbody>
</table>

- Detector performances and reconstruction proves to be robust against machine background
B → K^{(*)}vv: perspectives @ Belle II

- Extrapolation on full Belle II statistics on Belle HAD and SL analyses, assuming two times better $B_{\text{tag}}$ reconstruction efficiency:
  - observation with about 18 ab$^{-1}$
  - precision on the branching fraction at 50 ab$^{-1}$:

<table>
<thead>
<tr>
<th></th>
<th>stat only</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^+ \to K^+ vv$</td>
<td>9.5%</td>
<td>10.7%</td>
</tr>
<tr>
<td>$B^+ \to K^{*+} vv$</td>
<td>7.9%</td>
<td>9.3%</td>
</tr>
<tr>
<td>$B^+ \to K^{*0} vv$</td>
<td>8.2%</td>
<td>9.6%</td>
</tr>
</tbody>
</table>

- Fraction of longitudinally polarized $K^*$ may
  - be measured, $\sim 20\%$ precision with full statistics
- Robustness against machine background proved, predicted precision can be exceeded by improving analysis strategy
Belle II Physics Prospects – CKM

- Is the unitary triangle really a triangle
  Currently, $(\alpha + \beta + \gamma) = (175 \pm 9)^{\circ}$
- Angle $\phi_1(\beta)$ is measured with $1^{\circ}$ accuracy; angles $\phi_2(\alpha)$ and $\phi_3(\gamma) \sim 5 - 15^{\circ}$ accuracy
- Accuracies for $V_{cb} \sim 3\%; V_{ub} \sim 10\%; V_{td} \sim 7\%; V_{ts} \sim 6\%; V_{td} / V_{ts} \sim 3\%$

| $|V_{cb}|$ incl. | 1% |
|----------------|----|
| $|V_{cb}|$ excl. | 1.5% |
| $|V_{ub}|$ incl. | 3% |
| $|V_{ub}|$ excl. | 2% (w/LHCb) |

For a SM-like scenario

If the current WAs hold

- For details, please see Belle II physics book:
  https://confluence.desy.de/display/BII/B2TiP+ReportStatus