Belle II: Status and prospects

Yoshiyuki Onuki
On behalf of Belle II collaboration
Department of Physics
University of Tokyo, Japan
Outline

- SuperKEKB and BelleII detector
- Run plan
- Detector performance
- Selected topics
- Summary
**SuperKEKB**

- Very strong vertical focusing at the interaction point (IP)
- Increase beam current

### Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>KEKB</th>
<th>SuperKEKB</th>
<th>units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energy</td>
<td>$E_b$</td>
<td>$E_b$</td>
<td>GeV</td>
</tr>
<tr>
<td>bg</td>
<td>3.5</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Half crossing angle</td>
<td>$\phi$</td>
<td>11 (x20)</td>
<td>mrad</td>
</tr>
<tr>
<td>Beta functions at IP</td>
<td>$\beta_x^<em>/\beta_y^</em>$</td>
<td>1200/5.9 (x20)</td>
<td>mm</td>
</tr>
<tr>
<td>Beam currents</td>
<td>$I_b$</td>
<td>1.64 (x1.5)</td>
<td>A</td>
</tr>
<tr>
<td>Luminosity</td>
<td>$L$</td>
<td>$2.1 \times 10^{34}$</td>
<td>$6.5 \times 10^{35}$</td>
</tr>
</tbody>
</table>
• 2021b run ended July-5.
• New luminosity world record $3.1 \times 10^{34}$/cm$^2$/sec at off-resonance set on 22$^{nd}$ June 2021 (previous KEKB set $2.1 \times 10^{34}$/cm$^2$/sec on 2010).
• Data taking efficiency is almost achieved $\sim 90\%$ by improved efficient detector operation. The 2021a/b physics run makes statistics double. Now $\int L \sim 213$ fb-1.
Beauty, charm and tau-factory,

\[
\sigma(e^+ e^- \rightarrow \Upsilon(4S)) = 1.11 \text{ nb}
\]
\[
\sigma(e^+ e^- \rightarrow \Upsilon(5S)) = 0.3 \text{ nb}
\]
\[
\sigma(e^+ e^- \rightarrow \Upsilon(6S)) = 0.3 \text{ nb}
\]
\[
\sigma(e^+ e^- \rightarrow \Upsilon(4S)) = 1.11 \text{ nb}
\]
\[
\sigma(e^+ e^- \rightarrow \Upsilon(5S)) = 0.3 \text{ nb}
\]
\[
\sigma(e^+ e^- \rightarrow \Upsilon(6S)) = 0.3 \text{ nb}
\]

SuperKEKB/BelleII has a capability to cover the just below \(Y(1S)\) and just above \(Y(6S)\).

ISR
Two-photon
Exotic
Dark sector

See talk by Junhao Yin “Quarkonium at Belle II”
Belle II Detector

EM Calorimeter: CsI(Tl), waveform sampling (barrel)

Beryllium beam pipe
2cm diameter

Vertex Detector
2 layers Pixel + 4 layers Strip

Central Drift Chamber (CDC)
He(50%):C2H6(50%), Small cells, long lever arm, fast electronics

K_\mu detector: KLM
Resistive Plate (barrel)
Scint.+WLSF+MPPC (end-caps)

Focusing Aerogel RICH:
ARICH
Aerogel+HAPD for PID

Time-of-Propagation counter: TOP
Quartz+MCP PMT

Belle II/CDC  Belle/CDC

electron (7GeV)

positron (4GeV)
Run plan

- 2021 July-5. Total >213 fb-1
- 2021 Summer shutdown
- 2021 Autumn run.
  - Y(4S) ~400 fb-1 (BaBar)
  - 10.75GeV+scan for 10 fb-1 is planned.
- 2022 Summer ~700 fb-1 (Belle)
- 2022 Long shutdown1 (LS1)
  - Full pixel in the 2nd inner most layer
  - TOP PMT replacement
- 2026 ~15 ab-1
- 2031 ~50 ab-1
Tracking efficiency

Find a lepton and 2 good tracks with $\Sigma q_i = \pm 1$.
Find 4th track that passes $\Sigma q_i = 0$.
Count the events where the probe track is found ($N_4$) and not found ($N_3$):

$\varepsilon \times A = \frac{N_4}{N_4 + N_3}$

$A$: detector acceptance
$\varepsilon$: track reconstruction efficiency

After the calibration factor introduced, DATA/MC agrees in the broad $p_T$ range.
Particle ID

Each PID detector defines likelihood $\mathcal{L}_i$ for each charged particle hypothesis and the global likelihood is defined $\mathcal{L} = \prod \mathcal{L}_i$.

The global likelihood ratio of the particle $\ell$ can be defined:

$$\ell ID = \frac{\mathcal{L}_\ell}{\mathcal{L}_e + \mathcal{L}_\mu + \mathcal{L}_\pi + \mathcal{L}_K + \mathcal{L}_p}$$

1.13 ≤ $\theta$ < 1.57 [rad], electronID > 0.9

Belle II 2020 (Preliminary), $\int dt = 34.6$ [fb$^{-1}$]

0.82 ≤ $\theta$ < 1.16 [rad], muonID > 0.9

Belle II 2020 (Preliminary), $\int dt = 34.6$ [fb$^{-1}$]

KID $D^{*+} \to D^{0}[K^{-}\pi^+]\pi^+$

Shows good PID separation.
Neutral reconstruction

$\pi^0 \rightarrow \gamma \gamma$

$\eta \rightarrow \gamma \gamma$

$\eta \rightarrow 3\pi^0$

$K_\text{s} \rightarrow \pi^+ \pi^-$

Large solid angle and good uniformity detector → better reconstruction of neutrals. Also has capabilities
• to recover Bremsstrahlung photon
• to detect isolated ISR/FSR as well.
Vertexing

\[ \tau_{D^0} = 412.3 \pm 2.0 \text{ fs (stat only)} \]
\[ \text{W.A.} \tau_{D^0} = 410.1 \pm 1.5 \text{ fs} \]

Tagged D* decays
\[ D \rightarrow K\pi, K\pi\pi^0, K\pi\pi\pi \]

Pixel detector improves the vertex position resolution.

\[ \tau_{B^0} = 1.48 \pm 0.28 \pm 0.06 \text{ ps} \]
\[ \text{W.A.} \tau_{B^0} = 1.519 \pm 0.004 \text{ ps} \]
Flavor identification

Flavor id of tag-side B-meson: $B^0_{tag}$ or $\bar{B}^0_{tag}$? Wrong flavor tag fraction $w$ can dilute observed CP asymmetry: $A_{CP}^{Obs} = A_{CP}^{Raw} (1 - 2w)$

The $w$ can be estimated by flavor specific decay $B^0 \rightarrow D^{(*)h}$ mode with $q \cdot r_{FBDT}$

$$\frac{N_{OF} - N_{SF}}{N_{OF} + N_{SF}} = (1 - 2w) \cdot (1 - \chi_d)$$

$N_{OF}$: opposite flavor in $B_{sig}$ and $B_{tag}$
$N_{SF}$: same flavor in $B_{sig}$ and $B_{tag}$
$\chi_d$: mixing prob. (W.A. 0.1858 ± 0.0011).

$r_{FBDT}$ used binning the flavor tag in 7 bins to avoid possible MC bias $r_{FBDT}^i \approx 1 - 2w_i$

Effective Tag efficiency: $\varepsilon_{eff} = \Sigma \varepsilon_{tag}^i \cdot (1 - 2w_i)^2$

Belle II: $\varepsilon_{eff} = 33.8 \pm 3.6 \pm 1.6 \%$

Belle: $\varepsilon_{eff} = 30.1 \pm 0.4 \%$
Time-dependent CPV measurement

\[
S = \sin 2\phi_1 = 0.55 \pm 0.21 \text{(stat.)} \pm 0.04 \text{(syst.)}
\]

W.A. 0.695 ± 0.019

\[
\Delta m_d = (0.531 \pm 0.046 \text{(stat.)} \pm 0.013 \text{(syst.)}) \text{ps}
\]

W.A. 0.5065 ± 0.0019

\[
A(\Delta t) = \frac{N_{OF} - N_{SF}}{N_{OF} + N_{SF}} = \cos(\Delta m_d \Delta t)(1 - 2\omega)
\]

\[
A_{CP}(\Delta t) = \frac{\Gamma_{B^0}(\Delta t) - \Gamma_{B^0}(\Delta t)}{\Gamma_{B^0}(\Delta t) + \Gamma_{B^0}(\Delta t)} = S \sin \Delta m_d \Delta t + A \cos \Delta m_d \Delta t
\]
B$^+ \rightarrow K^+\nu\bar{\nu}$ decay w/ inclusive tagging

Unknown flavor of $\nu$. This mode may enhance from SM expectation.

$\text{Br}(B^+ \rightarrow K^+\nu\bar{\nu}) < 4.1 \times 10^{-5}$ (90% C.L.) using 63 fb$^{-1}$ Belle II

Already comparable result of hadronic tag in

$< 3.7 \times 10^{-5}$ (90% C.L.) BaBar Phys.Rev.D87,112005(2013)

$< 5.5 \times 10^{-5}$ (90% C.L.) Belle Phys.Rev.D87,1110103(2013)
Axion/ALPS and $Z'$ search

For $m_a > 6.85$ GeV/c$^2$

\[ E_{\text{rec}} = \frac{s - m_a^2}{2\sqrt{s}} \]

Candidates / (1 GeV/c$^2$)

For $m_a < 6.85$ GeV/c$^2$

\[ \gamma \gamma \]


\[
\begin{align*}
\mu^+\mu^- & \quad \text{mode} \\
\mu^\pm e^\mp & \quad \text{mode}
\end{align*}
\]

Belle can explore large parameter space in ALPS and to exploit the favored $g-2$ band in $L_{\mu-L_t}$ model.

Belle II 2018

ALPS

JHEP12(2017)094

JHEP12(2016)106


JHEP12(2017)094


Direct CPV $A_{CP}(K\pi)$

Direct CP asymmetry $A_{CP}(K^-\pi^+)$ is defined as:

$$A_{CP}(K^-\pi^+) = \frac{\Gamma(\bar{B}^0 \rightarrow K^-\pi^+)-\Gamma(B^0 \rightarrow K^+\pi^-)}{\Gamma(\bar{B}^0 \rightarrow K^-\pi^+)+\Gamma(B^0 \rightarrow K^+\pi^-)}$$

Measurement of $A_{CP}(B^0 \rightarrow K^+\pi^-)$ and $A_{CP}(B^+ \rightarrow K^+\pi^0)$: $\Delta A_{CP}(K\pi) = 0.0120 \pm 0.021$

The isospin sum rule test was proposed in Phys.Lett.B627(2005)82

$$I_{K\pi} = A_{K^+\pi^-} + A_{K^0\pi^+} + A_{K^0\pi^+} B(K^0\pi^+) \frac{\tau_B}{\tau_{B^0}} - 2A_{K^0\pi^0} B(K^+\pi^-) \frac{\tau_{B^0}}{\tau_B} - 2A_{K^0\pi^0} B(K^0\pi^0) B(K^+\pi^-) = 0$$

in SM. If non-zero, evidence of NP.

Simple expectation $\Delta A_{CP}(K\pi) \sim 0$

If Tree & Penguin are dominant. Suffering the hadronic uncertainty

$$A_{K^0\pi^0} = -0.40^{+0.46}_{-0.44} \text{(stat)} \pm 0.04 \text{(syst)}, \quad B(B^0 \rightarrow K^0\pi^0) = \left[8.5^{+1.7}_{-1.6} \text{(stat)} \pm 1.2 \text{(syst)}\right] \times 10^{-6}$$

arXiv:2104.14871 63 fb-1

Current W.A.(Belle+BaBar+LHCb+BelleII winter2021)

$I_{K\pi} = -0.11 \pm 0.13$

BelleII can contribute the determination the $I_{K\pi}$

See also arXiv:2105.04111
Summary

- SuperKEKB/BelleII are running stable.
  - Instantaneous $L = 3.1 \times 10^{34}$ /cm/sec recorded.
  - Integrated $L_{int} = 213$ fb-1 accumulated now.
  - 400 fb-1 @$Y(4S)$ and energy scan are planned in this year.
  - Deepen understanding of our detector

- Various analyses on going
  - Results with better precision than Belle/BaBar will be appeared soon.