KEKB Accelerator

8.0 GeV e⁻
3.5 GeV e⁺
KEKB Performance

➢ World record luminosity: $2.1 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1} \rightarrow \text{Twice design}$
➢ $1 \text{ ab}^{-1}$ of integrated luminosity
Achievements of B-factories

➢ Observation of mixing-induced CP violation in $B^0$ system

• Precision measurement of $\sin(2\Phi_1)$
• Observation of direct CPV in B decays
• Measurements of rare decays ($b \to s\gamma$, $b \to s l^+ l^-$, $B \to \tau \nu$, ...)
• Observation of $D^0$ mixing
• LFV searches in $\tau$ decays
• $B_s$ physics at $Y(5S)$
• Observation of new (exotic) hadrons ($\eta_b$, $h_b$, $X(3872)$, $Z_b^+$, ...)

➔ Very rich physics program!
Why A Super Flavor Factory?

- We know there has to be New Physics somewhere
  - Atlas and CMS have not found it (yet?)
- Precision flavor physics measurement may reveal the NP (like in the past)
  - Some hints exist
- Several measurements can only be done at B factories and are still limited by statistics
Full Reconstruction at B Factories

- Full reconstruction of hadronically decaying B meson
  - Momentum and charge of signal B known
  - All remaining particles belong to the signal B
  - Reconstruction of $B \rightarrow D^{(*)}\tau\nu$, $B \rightarrow \tau\nu$, $B \rightarrow K\nu\nu$, $B \rightarrow \nu\nu$, ...

\[ B^+ \rightarrow D^0\pi^+ \]
\[ (\rightarrow K\pi^-\pi^+\pi^-) \]
\[ B^- \rightarrow \tau (\rightarrow e\nu\bar{\nu})\nu \]
Projections for 50 ab$^{-1}$

<table>
<thead>
<tr>
<th>Observable</th>
<th>Belle 2006 (≈0.5 ab$^{-1}$)</th>
<th>SuperKEKB (5 ab$^{-1}$)</th>
<th>SuperKEKB (50 ab$^{-1}$)</th>
<th>$^\dagger$LHCb (2 fb$^{-1}$)</th>
<th>$^\dagger$LHCb (10 fb$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leptonic/semileptonic $B$ decays</td>
<td>$B(B^+ \to \tau^+\nu)$</td>
<td>3.5$\sigma$</td>
<td>10%</td>
<td>3%</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>$B(B^+ \to \mu^+\nu)$</td>
<td>$^\dagger\dagger&lt;2.4B_{SM}$</td>
<td>4.3 ab$^{-1}$ for 5$\sigma$ discovery</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>$B(B^+ \to D\tau\nu)$</td>
<td>-</td>
<td>8%</td>
<td>3%</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>$B(B^0 \to D\tau\nu)$</td>
<td>-</td>
<td>30%</td>
<td>10%</td>
<td>-</td>
</tr>
<tr>
<td>LFV in $\tau$ decays (U.L. at 90% C.L.)</td>
<td>$B(\tau \to \mu\gamma)$ [10$^{-9}$]</td>
<td>45</td>
<td>10</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>$B(\tau \to \mu\eta)$ [10$^{-9}$]</td>
<td>65</td>
<td>5</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>$B(\tau \to \mu\mu\mu)$ [10$^{-9}$]</td>
<td>21</td>
<td>3</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>$B(B^+ \to K^+\nu\nu)$</td>
<td>$^\dagger\dagger&lt;3B_{SM}$</td>
<td>30%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>$B(B^0 \to K^*0\nu\nu)$</td>
<td>$^\dagger\dagger&lt;40B_{SM}$</td>
<td>35%</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

![Diagram](image)

\[ \frac{-\text{Re}(C_L^\nu C_R^{\nu^+})}{|C_L^\nu|^2 + |C_R^{\nu^+}|^2} \]
<table>
<thead>
<tr>
<th>Observable</th>
<th>Belle 2006 (≈0.5 ab⁻¹)</th>
<th>SuperKEKB (5 ab⁻¹)</th>
<th>(50 ab⁻¹)</th>
<th>†LHCb (2 fb⁻¹)</th>
<th>(10 fb⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unitarity triangle parameters</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sin²φ₁</td>
<td>0.026</td>
<td>0.016</td>
<td>0.012</td>
<td>~0.02</td>
<td>~0.01</td>
</tr>
<tr>
<td>φ₂ (ππ)</td>
<td>11°</td>
<td>10°</td>
<td>3°</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>φ₂ (ρπ)</td>
<td>68° &lt; φ₂ &lt; 107°</td>
<td>3°</td>
<td>1.5°</td>
<td>10°</td>
<td>4.5°</td>
</tr>
<tr>
<td>φ₂ (ρρ)</td>
<td>62° &lt; φ₂ &lt; 107°</td>
<td>3°</td>
<td>1.5°</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>φ₂ (combined)</td>
<td>2°</td>
<td>&lt; 1°</td>
<td>10°</td>
<td>4.5°</td>
<td></td>
</tr>
<tr>
<td>φ₃ (D(<em>)K(</em>)ₜ) (Dalitz mod. ind.)</td>
<td>20°</td>
<td>7°</td>
<td>2°</td>
<td>8°</td>
<td></td>
</tr>
<tr>
<td>φ₃ (D(*)Kₜ) (ADS+GLW)</td>
<td>-</td>
<td>16°</td>
<td>5°</td>
<td>5-15°</td>
<td></td>
</tr>
<tr>
<td>φ₃ (D(*)π)</td>
<td>-</td>
<td>18°</td>
<td>6°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>φ₃ (combined)</td>
<td></td>
<td>6°</td>
<td>1.5°</td>
<td>4.2°</td>
<td>2.4°</td>
</tr>
<tr>
<td></td>
<td>Vub</td>
<td>(inclusive)</td>
<td>6%</td>
<td>5%</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>Vub</td>
<td>(exclusive)</td>
<td>15%</td>
<td>12% (LQCD)</td>
<td>5% (LQCD)</td>
</tr>
<tr>
<td>††† p</td>
<td>20.0%</td>
<td></td>
<td>3.4%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>††† ê</td>
<td>15.7%</td>
<td></td>
<td>1.7%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Projections for 50 ab\(^{-1}\)

<table>
<thead>
<tr>
<th>Observable</th>
<th>Belle 2006 (~0.5 ab(^{-1}))</th>
<th>SuperKEKB (5 ab(^{-1}))</th>
<th>(50 ab(^{-1}))</th>
<th>(\dagger)LHCb (2 fb(^{-1}))</th>
<th>(10 fb(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\Delta S_{\phi K^0})</td>
<td>0.22</td>
<td>0.073</td>
<td>0.029</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td>(\Delta S_{\eta' K^0})</td>
<td>0.11</td>
<td>0.038</td>
<td>0.020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\Delta S_{K_S^0 K_S^0 K_S^0})</td>
<td>0.33</td>
<td>0.105</td>
<td>0.037</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>(\Delta A_{\pi^0 K_S^0})</td>
<td>0.15</td>
<td>0.072</td>
<td>0.042</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>(A_{\phi \phi K^+})</td>
<td>0.17</td>
<td>0.05</td>
<td>0.014</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\phi^e f_f (\phi K_S) \text{ Dalitz})</td>
<td>3.3°</td>
<td>1.5°</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Diagrams

- **Left Diagram:**
  - \(C_{CP} = -A_{CP}\) vs \(\sin(2\beta_{\text{eff}}) = \sin(2\phi_{1\text{eff}})\)
  - HFAG (Montrou 2012)
  - PRELIMINARY

- **Right Diagram:**
  - Belle (July 2006, 492 fb\(^{-1}\)) vs SuperKEKB (50 ab\(^{-1}\))
  - Contours give \(-2\Delta\ln L = \Delta\chi^2 = 1\), corresponding to 68.3% CL for 2 dof
  - New Physics:
    - SUSY GUT, Warped Extra Dimension,
    - String-inspired MSSM, ...
  - \(\Delta S_{\phi K^0}\) vs Integrated luminosity (ab\(^{-1}\))
  - \(\Delta S_{\eta' K^0}\)
  - \(\Delta S_{K_S^0 K_S^0 K_S^0}\)
  - \(\Delta S_{\pi^0 K_S^0}\)

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*arXiv:1002.5012*
Aim For 50 ab$^{-1}$

![Graph showing the peak luminosity trends for e+e- colliders with SuperKEKB as a target, achieving $8 \times 10^{35}$ cm$^{-2}$ s$^{-1}$ by 2020.]
Accelerator Design: Nano Beam Scheme

Invented by Pantaleo Raimondi for SuperB

\[ L = \frac{\gamma_{\pm}}{2er_e c} \left( 1 + \frac{\sigma_y^*}{\sigma_x^*} \right) I_{\pm} \xi_{y\pm} \frac{R_L}{R_{\xi_y}} \]

<table>
<thead>
<tr>
<th></th>
<th>(\beta_x^*) (cm)</th>
<th>(\beta_y^*) (mm)</th>
<th>(\xi_y)</th>
<th>(\epsilon_x) (nm)</th>
<th>(I_{\text{beam}}) (A)</th>
<th>(L) (cm(^{-2}) s(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>KEKB w/ crab</td>
<td>120/120</td>
<td>5.9/5.9</td>
<td>0.13/0.09</td>
<td>18/24</td>
<td>1.6/1.2</td>
<td>2.11 x 10(^{34})</td>
</tr>
<tr>
<td>SuperKEKB</td>
<td>3.2/2.5</td>
<td>0.27/0.31</td>
<td>0.09/0.08</td>
<td>3.2/5.0</td>
<td>3.6/2.6</td>
<td>80 x 10(^{34})</td>
</tr>
</tbody>
</table>

\[ \xi_y \propto \sqrt{\beta_y^*/\epsilon_y} \]

Geometrical reduction factors (crossing angle, hourglass effect)
SuperKEKB Upgrade

- **SuperKEKB Upgrade**
- **e- 2.6 A**
- **e+ 3.6 A**
- **Damping ring**
- **Low emittance gun**
- **Positron source**
- **New beam pipe & bellows**
- **Belle II**
- **New IR**
- **New superconducting/permanent final focusing quads near the IP**
- **TiN-coated beam pipe with antechambers**
- **Redesign the lattices of HER & LER to squeeze the emittance**
- **Add / modify RF systems for higher beam current**
- **New positron target / capture section**
- **New beam pipe & bellows**
- **Low emittance positrons to inject**
- **Positron source**
- **New positron target / capture section**
- **Low emittance gun**
- **Low emittance electrons to inject**
- **Replace short dipoles with longer ones (LER)**
- **Larger crossing angle**
  - \(2\phi = 22\) mrad \(\rightarrow\) 83 mrad
- **Smaller asymmetry**
  - 3.5 / 8 GeV \(\rightarrow\) 4 / 7 GeV
SuperKEKB Construction

➢ Installation of first dipole magnet on February 7, 2012
SuperKEKB Construction

➢ Damping ring construction started

18/Jan/2012

13/May/2012

13/May/2012
Belle II Detector Compared with Belle

- Higher background, higher event rate
Background Simulation

- **RBB**
- **LER**
- **RBB**
- **HER**
- **Touschek**
- **HER**
- **Coulomb**
- **HER**

Neutrons (rad. Bhabha)
Belle II Detector

**Electrons (7 GeV)**
- EM Calorimeter: CsI(Tl), waveform sampling (barrel)
- Pure CsI + waveform sampling (end-caps)

**Positrons (4 GeV)**
- K_L and muon detector:
  - Resistive Plate Counter (barrel)
  - Scintillator + WLSF + MPPC (end-caps)

**Beryllium beam pipe**
- 2cm diameter

**Vertex Detector**
- 2 layers DEPFET + 4 layers DSSD

**Central Drift Chamber**
- He(50%):C_2H_6(50%), small cells, long lever arm, fast electronics

**Particle Identification**
- Time-of-Propagation counter (barrel)
- Prox. focusing Aerogel RICH (fwd)
Beam Pipe and Pixel Detector

Beryllium beam pipe
2cm diameter

Vertex Detector
2 layers DEPFET

Significant improvement in vertex resolution

Impact parameter resolution $z_0$
Silicon Strip Detector

Vertex Detector
4 layers DSSD

Improvement in $\delta S(K_S \pi^0 \gamma)$ because of larger $K_S$ acceptance (by $\sim 30\%$)
Drift Chamber

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

- Reduced dead time because of new electronics: 1-2 μs → 200 ns

- Better momentum resolution because of larger outer radius

\[ \frac{\sigma_{p_t}}{p_t} = \sqrt{(0.2\%p_t)^2 + (0.3%/\beta)^2} \]
Barrel Particle Identification

Simulation

\( p = 2 \text{ GeV/c}, \theta = 90 \text{ deg} \)

Compact design, Improved K/\pi separation

Barrel Particle Identification Time-of-Propagation counter
Endcap Particle Identification

Improved K/π separation

Endcap Particle Identification
Prox. focusing Aerogel RICH

Testbeam
EM Calorimeter

EM Calorimeter: CsI(Tl), waveform sampling (barrel)
Pure CsI + waveform sampling (end-caps)

Better signal to background separation because of waveform sampling and pure CsI in endcaps
$K_L$ and Muon Detector

Replacement of PRCs in endcaps and inner barrel layers with scintillators to tolerate high background rates

$K_L$ and muon detector:
- Resistive Plate Counter (barrel)
- Scintillator + WLSF + MPPC (end-caps)
Software Upgrade

➢ New framework with dynamic module loading, parallel processing, python steering, and root I/O

● Full detector simulation with Geant4

● Tracking with GenFit
Estimated Data Rates

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Event Size [kB]</th>
<th>Rate [Hz]</th>
<th>Rate [MB/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High rate scenario for Belle II DAQ:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belle II</td>
<td>300</td>
<td>6,000</td>
<td>1,800</td>
</tr>
<tr>
<td><strong>LCG TDR (2005):</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALICE (HI)</td>
<td>12,500</td>
<td>100</td>
<td>1,250</td>
</tr>
<tr>
<td>ALICE (pp)</td>
<td>1,000</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>ATLAS</td>
<td>1,600</td>
<td>200</td>
<td>320</td>
</tr>
<tr>
<td>CMS</td>
<td>1,500</td>
<td>150</td>
<td>225</td>
</tr>
<tr>
<td>LHCb</td>
<td>25</td>
<td>2,000</td>
<td>50</td>
</tr>
</tbody>
</table>
Computing Model

Raw Data Storage and Processing

MC Production and Ntuple Production

Ntuple Analysis

MC Production (optional)
Belle II Collaboration

~400 members
65 institutes
from 19 countries
Schedule

Will reach $50 \text{ ab}^{-1}$ in 2022

Physics run starts end of 2015

Commissioning starts end of JFY 2014

Shutdown for upgrade
Funding Status

➢ SuperKEKB fully funded
   • Approved by Japanese government in December 2010 and by Japanese Diet (parliament) in March 2011

➢ Belle II detector 50% funded by Japanese government

➢ Funding in other countries requested or already approved

➔ First MoU signed with German funding agencies Nov. 2011
Groundbreaking Ceremony

→ November 18, 2011
Conclusions

Unexplored region

LHCb

Belle II

SuperB

Atlas/CMS

Higgs

12th Open Meeting in Bad Aibling July 22-25
Backup
Belle and BaBar Datasets

\[ (> 1 \text{ ab}^{-1}) \]
\[ \text{On resonance:} \]
\[ \Upsilon(5S): 121 \text{ fb}^{-1} \]
\[ \Upsilon(4S): 711 \text{ fb}^{-1} \]
\[ \Upsilon(3S): 3 \text{ fb}^{-1} \]
\[ \Upsilon(2S): 25 \text{ fb}^{-1} \]
\[ \Upsilon(1S): 6 \text{ fb}^{-1} \]
\[ \text{Off resonance/scan:} \]
\[ \sim 100 \text{ fb}^{-1} \]

\[ \sim 550 \text{ fb}^{-1} \]
\[ \text{On resonance:} \]
\[ \Upsilon(4S): 433 \text{ fb}^{-1} \]
\[ \Upsilon(3S): 30 \text{ fb}^{-1} \]
\[ \Upsilon(2S): 14 \text{ fb}^{-1} \]
\[ \text{Off resonance:} \]
\[ \sim 54 \text{ fb}^{-1} \]
Detailed Schedule
\( \tau \to \mu \gamma \)

\[
\tau \to \mu \gamma / \tau \to \pi \nu \\
\cos \theta^* (\mu^-)
\]

\( h \tau^- = +1 \)

\[
\tau \to \mu \nu \nu / \tau \to \pi \nu \\
\cos \theta^* (\pi +)
\]

\( h \tau^- = -1 \)

study by K. Hayaska