SuperKEKB
WIN2009
September 18, 2009
Masa Yamauchi
KEK
Outline

- Introduction: KEKB and Belle
- Physics at SuperKEKB/Belle-II
- Accelerator upgrade plan
- Detector upgrade plan
- Summary
KEKB and Belle

- **TSUKUBA Area**
- **OHO Area**
- **HER** (High Energy Ring)
- **LER** (Low Energy Ring)
- **NIKKO Area**
- **FUJI Area**

**Annotations:**
- Electron
- Positron
- WIGGLER
- RF
- (TRISTAN Accumulation Ring)
Achievement of the B Factories

Discovery of CP violation in BB system

Belle, July 05

$B^0 \rightarrow J/\psi K_S$

$\bar{B}^0 \rightarrow J/\psi K_S$

Confirmation of KM mechanism
Possible hints for NP?

Difference in CPV between $B^0$ and $B^\pm$

- Anomalous CPV in $b \rightarrow s$ processes?
- Anomaly in $B \rightarrow K^{*}ll$ decay?

Inconsistency in unitarity triangle?

Unexpectedly large $D^0\bar{D}^0$ oscillation
What is next with flavour physics?

- LHC will start soon to explore the TeV region, which is the scale of the electroweak symmetry breaking, and most probably related to the “New Physics” scale.
  - It is natural to assume that the NP effects are seen in $B/D/\tau$ decays.
  - Flavour structure of new physics?
  - CP violation in new physics?
  - These studies will be useful to identify mechanism of SUSY breaking, if NP=SUSY.

- Otherwise...
  - Search for deviations from SM in flavor physics will be one of the best ways to find new physics.

In order for the flavor physics to be useful in the coming LHC era, the precision of various flavor measurements must be significantly improved, both in terms of experimental reach and understanding of theoretical uncertainty.
Target luminosity: $8 \times 10^{35} \text{cm}^{-2}\text{s}^{-1}$

Will lead to 50ab$^{-1}$ before 2020.
### Key measurements

<table>
<thead>
<tr>
<th></th>
<th>Belle'06 (~0.5ab(^{-1}))</th>
<th>5ab(^{-1})</th>
<th>50ab(^{-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>
</tr>
<tr>
<td>(\Delta S(\eta' K^0))</td>
<td>0.11</td>
<td>0.038</td>
<td>0.020</td>
</tr>
<tr>
<td>(\Delta S(K_S K_S K_S))</td>
<td>0.33</td>
<td>0.105</td>
<td>0.037</td>
</tr>
<tr>
<td>(\Delta S(K_S \pi^0 \gamma))</td>
<td>0.32</td>
<td>0.10</td>
<td>0.03</td>
</tr>
<tr>
<td>(\text{Br}(X_S \gamma))</td>
<td>13%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(A_{CP}(X_S \gamma))</td>
<td>0.058</td>
<td>0.01</td>
<td>0.005</td>
</tr>
<tr>
<td>(C_9 [A_{FB}(K^*\pi\pi)])</td>
<td>---</td>
<td>11%</td>
<td>4%</td>
</tr>
<tr>
<td>(C_{10} [A_{FB}(K^*\pi\pi)])</td>
<td>---</td>
<td>3%</td>
<td>4%</td>
</tr>
<tr>
<td>(\text{Br}(B^+ \rightarrow K^*\nu\nu))</td>
<td>&lt;9\text{Br}(SM)</td>
<td>33ab(^{-1}) for 5\sigma discovery</td>
<td></td>
</tr>
<tr>
<td>(\text{Br}(B^+ \rightarrow \tau\nu))</td>
<td>3.5\sigma</td>
<td>10%</td>
<td>3%</td>
</tr>
<tr>
<td>(\text{Br}(B^+ \rightarrow \mu\nu))</td>
<td>&lt;2.4Br(SM)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\text{Br}(B^+ \rightarrow D\tau\nu))</td>
<td>---</td>
<td>7.9%</td>
<td>2.5%</td>
</tr>
<tr>
<td>(\text{Br}(\tau \rightarrow \mu\gamma))</td>
<td>&lt;45</td>
<td>&lt;30</td>
<td>&lt;8</td>
</tr>
<tr>
<td>(\text{Br}(\tau \rightarrow \mu\eta))</td>
<td>&lt;65</td>
<td>&lt;20</td>
<td>&lt;4</td>
</tr>
<tr>
<td>(\text{Br}(\tau \rightarrow 3\mu))</td>
<td>&lt;209</td>
<td>&lt;10</td>
<td>&lt;1</td>
</tr>
<tr>
<td>(\Delta \sin 2\phi_1)</td>
<td>0.026</td>
<td>0.016</td>
<td>0.012</td>
</tr>
<tr>
<td>(\Delta \Phi_2 (\rho\pi))</td>
<td>68°—95°</td>
<td>3°</td>
<td>1°</td>
</tr>
<tr>
<td>(\Delta \Phi_3 (\text{Dalitz}))</td>
<td>20°</td>
<td>7°</td>
<td>2.5°</td>
</tr>
<tr>
<td>(\Delta V_{ub} (\text{incl.}))</td>
<td>7.3%</td>
<td>6.6%</td>
<td>6.1%</td>
</tr>
</tbody>
</table>

**CPV in** \(b \rightarrow s\) **modes**

**FCNC**  \(b \rightarrow s\gamma\)

**\(b \rightarrow sll\)**

**Tauonic decays**

**LFV tau decays**

**Precision CKM**
**Very precise test of CKM scheme**

This is to search for new physics contribution in $b \rightarrow d$ transition.

50 $ab^{-1}$

$\Delta \sin 2\phi_1 = 0.014$

$\Delta (f_B \sqrt{B_d}) = 0.005 \pm 0.01$

$\Delta |V_{ub}| = 4.4\%$

$\Delta \phi_3 = 1.2^\circ$
CPV in $b \to s$ penguin

SM

NP

$A_{CP}(t) = \sin(2(\phi_{CP} + \phi_{NP})) \times \sin(\frac{m_d}{2})$

Present upper limits

Measurements at SuperKEKB

Present B factories

SuperKEKB

New Physics
(SUSY GUT, Warped Extra Dimension, String-inspired MSSM, ...)

Deviation from SM

Contours give $-2\chi^2$ = 1, corresponding to 60.7% CL for 2 dof
Probing $b \rightarrow s$ transition with $l^+l^-$

: Probe the flavor changing process with the “EW probe”.

This measurement is especially sensitive to new physics such as SUSY, heavy Higgs and extra dim.

The F/B asymmetry is a consequence of $\gamma-Z^0$ interference.

MC with 50ab$^{-1}$
$H^\pm$ search in $B$ to $\tau$ decays

$B (B \rightarrow \tau \nu) = (1.73 \pm 0.35) \times 10^{-4}$

$B \rightarrow \tau \nu$: H-b-u coupling
$B \rightarrow D \tau \nu$: H-b-c coupling
$gb \rightarrow tH$: H-b-t coupling
Search for LFV $\tau$ decays

T.Goto et al., 2007

SuperKEKB
Strategy: Nano-Beam Option

**Beam-current**

\[ L = \frac{\gamma_{e^\pm} e^\pm}{2e\gamma e^\pm} \left(1 + \frac{\sigma^*_y}{\sigma^*_x} \right) \left( \frac{I_{e^\pm} \xi_{y}^{\pm}}{\beta_{y}^*} \right) \frac{R_L}{R_{\xi_{y}^{\pm}}} \]

**Bem-beam parameter**

Lorenz factor

Classical electron radius

Beam-size ratio@IP

1 ~ 2 % (flat beam)

Vertical beta function@IP

**Strategy Options**

1. **Smaller \( \beta_y^* \)**
   - \(6.5 (LER)/5.9 (HER) \) mm \(\rightarrow\) \(0.22/0.22\) mm

2. **Increase beam currents**
   - \(1.7\) A (LER) / \(1.4\) A (HER) \(\rightarrow\) \(2.96\) A (LER) / \(1.5\) A (HER)
     - Close to original KEKB design

3. **Increase \( \xi_y \)**
   - \(0.1\) (LER)/\(0.06\) (HER) \(\rightarrow\) \(0.07/0.07\)

Proposed by P. Raimondi et al., along with Crab Waist, for use at Italian Super B Factory
## Beam parameters

<table>
<thead>
<tr>
<th></th>
<th>KEKB Design</th>
<th>KEKB Achieved (with crab)</th>
<th>SuperKEKB High-Current</th>
<th>SuperKEKB Nano-Beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (GeV) (LER/HER)</td>
<td>3.5/8.0</td>
<td>3.5/8.0</td>
<td>3.5/8.0</td>
<td>4.0/7.0</td>
</tr>
<tr>
<td>$\beta_y^*$ (mm)</td>
<td>10/10</td>
<td>5.9/5.9</td>
<td>3/6</td>
<td>0.27/0.42</td>
</tr>
<tr>
<td>$\varepsilon_x$ (nm)</td>
<td>18/18</td>
<td>18/24</td>
<td>24/18</td>
<td>3.2/1.7</td>
</tr>
<tr>
<td>$\sigma_y$ ($\mu$m)</td>
<td>1.9</td>
<td>0.94</td>
<td>0.85/0.73</td>
<td>0.059</td>
</tr>
<tr>
<td>$\xi_y$</td>
<td>0.052</td>
<td>0.129/0.090</td>
<td>0.3/0.51</td>
<td>0.09/0.09</td>
</tr>
<tr>
<td>$\sigma_z$ (mm)</td>
<td>4</td>
<td>~ 6</td>
<td>5/3</td>
<td>6/5</td>
</tr>
<tr>
<td>$I_{\text{beam}}$ (A)</td>
<td>2.6/1.1</td>
<td>1.64/1.19</td>
<td>9.4/4.1</td>
<td>3.6/2.6</td>
</tr>
<tr>
<td>$N_{\text{bunches}}$</td>
<td>5000</td>
<td>1584</td>
<td>5000</td>
<td>2500</td>
</tr>
<tr>
<td>Luminosity ($10^{34}$ cm$^{-2}$ s$^{-1}$)</td>
<td>1</td>
<td>2.11</td>
<td>53</td>
<td>80</td>
</tr>
</tbody>
</table>

*Multiplied by 40:*
Colliding bunches

New superconducting / permanent final focusing quads near the IP

Replace long TRISTAN dipoles with shorter ones (HER)

TiN-coated beam pipe with antechambers

Redesign the HER arcs to squeeze the emittance

Add / modify RF systems for higher beam current

Low emittance positrons to inject

Positron source

New positron target / capture section

Low emittance gun

Low emittance electrons to inject

SuperKEKB

x 40 Gain in Luminosity
# Keys in beam optics

<table>
<thead>
<tr>
<th>Low emittance</th>
<th>LER</th>
<th>HER</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Longer bends</td>
<td>• Increase number of arc cells</td>
<td></td>
</tr>
<tr>
<td>• 0.89 m to 4 m long</td>
<td>• Smaller dispersion in bends</td>
<td></td>
</tr>
<tr>
<td>• 0.89 m to 4 m long</td>
<td>• 28 cells to 44 cells</td>
<td></td>
</tr>
<tr>
<td>• 5.4 m to 3.6 m long</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Low beta at IP</th>
<th>LER</th>
<th>HER</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Separated final quads.</td>
<td>• Superconducting or permanent magnets</td>
<td></td>
</tr>
<tr>
<td>• Closer to IP</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Local chromaticity correction (LCC) (to get large DA)</th>
<th>LER</th>
<th>HER</th>
</tr>
</thead>
<tbody>
<tr>
<td>• KEKB-LER type</td>
<td>• S-shape type (modified SuperB/ILC LCC)</td>
<td></td>
</tr>
<tr>
<td>• Chicane-like (reverse bends)</td>
<td>• Bending angle is necessary (no reverse bends).</td>
<td></td>
</tr>
<tr>
<td>• Geometrical flexibility</td>
<td>• Small emittance generation.</td>
<td></td>
</tr>
<tr>
<td>• Emittance is generated.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The Problem of Electron Clouds

- Photo-electrons produced at the beam pipe wall by synchrotron radiation, and secondary electrons produced by electron-wall collisions, are trapped in the region of the beam orbit in the positron ring (LER).
- The KEKB LER has suffered beam blow-up and luminosity loss due to interactions with these electron clouds, which cause a fast head-tail instability.
- Bunch-current blowup threshold can be raised by the use of solenoids around the beam pipe.

However, KEKB performance is still limited by electron clouds.
Copper beam duct with ante-chambers

- Copper is required to withstand intense SR power

Features (compared to simple pipe):

- Low SR power density
- Low photoelectrons in beam pipe
- Low beam impedance
More on suppressing photoelectrons

TiN (Titanium nitride) coating on inner surface
- Decrease secondary electron yield (SEY): Max. SEY ~0.9
- A test stand for the coating was built in KEK, and applied to a test duct with ante-chambers.
  - Decrease of electrons at high current region was demonstrated.
And more on suppressing photoelectrons

**Clearing Electrode**
- Can be used inside magnet, where solenoid fields are ineffective.

**Grooved Surface (M. Pivi, SLAC)**
- Can also be used inside magnet.
- Mechanically traps photoelectrons.

Effectiveness of both designs in reducing electron clouds has been demonstrated at KEKB LER.

R&D continuing in collaboration with Cornell (CesrTA) and SLAC.
More for lower impedance: Bellows and gate valves

Comb-type RF shield is adaptable to a complicated aperture of beam duct with antechambers.

Bellows

Gate valve

Air cylinder

Inside view

outer appearance

Y.Suetsugu et.al

mm 12/10/2008
Luminosity projection

Projection of Luminosity

Integrated Luminosity (lab)

Year

- Shutdown for Upgrade
- Learning Curve

1.2 /ab/month
(8 x10^{35} /cm^2/s)

0.9 /ab/month
(6 x10^{35} /cm^2/s)

0.6 /ab/month
(4 x10^{35} /cm^2/s)

50 /ab
Belle-II detector

SVD: 4 DSSD lyr → 2 DEPFET lyr + 4 DSSD lyr
CDC: small cell, long lever arm
ACC+TOF → TOP+A-RICH
ECL: waveform sampling, pure CsI for end-caps
KLM: RPC → Scintillator +SiPM (end-caps)

Parameters are preliminary
Nano beam option: 1 cm radius of beam pipe

- 2 layer Si pixel detector (DEPFET technology) (R = 1.3, 2.2 cm) monolithic sensor thickness 50 µm (!), pixel size ~50 x 50 µm²
- 4 layer Si strip detector (DSSD) (R = 3.8, 8.0, 11.5, 14.0 cm)

Significant improvement in z-vertex resolution

\[ \sigma = a + \frac{b}{p \beta \sin^{5/2} \theta} \]

Belle II:
\[ a = 8.5 [nm] \]
\[ b = 9.6 [mm GeV^-] \]

PXD

“PXD“

SVD

“SVD“

PXD+SVD

Belle

Belle II

30 µm

15 µm

p\(\beta\)sin(\(\theta\)) [GeV/c]
Barrel PID

- Cherenkov ring imaging detector with precise timing information
  - Quartz radiator
    - 2cm T x ~40cm W x ~2.5m L
  - Possible configurations
    - 1-bar or 2-bar
    - Small stand-off box or not
  - MCP-PMT
    - Two candidates
      - Hamamatsu SL10 or Photonis 85015
    - Excellent time resolution (<40ps) required for good K/π separation; confirmed on laser bench
  - Electronics
    - Fast waveform sampling
      - New ASIC chip ready soon

Hamamatsu SL10

Laser test

σ=34.2±0.4ps
GaAsP MCP-PMT; QE distribution

- Better QE
  - >35% at 500nm
- Less chromatic error
- Lifetime test has started.
  - Need to check the QE degradation
Aerogel RICH for endcap PID

“Focusing” Aerogel radiator

Photon Sensors

- Sensitive to single photon
  - High QE >~ 20 %
  - High gain
- Position detection accuracy: ~5x5 mm²
- Large effective area:
- Operational with 1.5

N_{pe} = 9.1, \sigma(\text{track}) = 4.2 \text{ mrad achieved}

~5.5\sigma \text{ separation for 4 GeV/c K/\pi}

Hybrid (Avalanche) Photon Detector
MCP (Micro Channel Plate) PMT
Si-PM/MPPC
**SiPM main features:**
- Sensitive size $1\times1\text{mm}^2$ on chip $1.5\times1.5\ \text{mm}^2$
- Gain $2\times10^6$
- $U_{\text{bias}} \sim 50\text{V}$
- Recovery time $\sim 100\ \text{ns/pixel}$
- Number of pixels: 576-1024
- Insensitive to magnetic field
- Dynamic range $\sim 10^3/\text{mm}^2$
— ITEP scintillator 1m×1m test module (96 readout ch.)

**Test Module**

Housed in an aluminum box.

**Scintillator Strip with SiPM**

These modules will be installed in Oho side.
## Belle-II Collaboration has been formed

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004.06</td>
<td>SuperKEKB LoI</td>
</tr>
<tr>
<td>2008.01</td>
<td>KEK Roadmap</td>
</tr>
<tr>
<td>2008.03</td>
<td>1st Proto collaboration meeting</td>
</tr>
<tr>
<td>2008.10</td>
<td>Detector study report</td>
</tr>
<tr>
<td>2008.12</td>
<td>New collaboration, Belle-II, started</td>
</tr>
<tr>
<td></td>
<td>~300 collaborators from 43 institutions in 13 countries</td>
</tr>
<tr>
<td></td>
<td>Peter Krizan (Ljubljana) elected as the first spokesperson</td>
</tr>
<tr>
<td>2009.11</td>
<td>4th open collaboration meeting</td>
</tr>
</tbody>
</table>

*Photo of Belle-II collaboration meeting*
Summary

- Next generation $e^+e^- B$ factory with $L \sim 10^{36}$ is very useful to study the new sources of flavor mixing and CP violation, which is anticipated to be at $O(1\text{TeV})$ energy scale.

- SuperKEKB: Nano-beam scheme with the goal $L \sim 8 \times 10^{35}$.

- Belle-II: Detector upgrade to improve its performance and BKG/rate immunity.

- New collaboration, Belle-II, has been formed. An open meeting is scheduled on November 18-20 at KEK.

- We hope to have another friendly competition with Frascati SuperB.