SuperKEKB

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Flavour Physics at the Era of the LHC
@CERN

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KEK
Outline

- Introduction
- Achievements of the $B$ factories and the next step
- SuperKEKB: physics
- SuperKEKB: detector and schedule
- Situation at KEK and internationalization of the project
- Summary
Achievements of the $B$ Factories

Quantitative confirmation of the KM theory

- $|V_{ub}| = (4.35 \pm 0.52) \times 10^{-3}$
- $\Delta m_d = 0.511 \text{ps}^{-1}$
- $|V_{td}/V_{ts}| = 0.200 \pm 0.046$
- $75^\circ < \phi_2 < 113^\circ$
- $22^\circ < \phi_3 < 113^\circ$
- $\sin 2\phi_1 = 0.728 \pm 0.061$
- $|V_{cb}| = (4.08 \pm 0.27) \times 10^{-2}$

(Belle, 2005)
Another important achievement

Asymmetric $e^+e^-$ collider with $L > 10^{34}$

- Success of KEKB and PEP-II enabled us to design a new $e^+e^-$ B factory with much higher $L_{\text{peak}}$. 
What is next with $B$ physics?

- If new physics at $O(1)$TeV…
  - It is natural to assume that the 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.
New physics effect in $B$ decays

G. Hiller

Likelihood for the effects of new physics to be seen in $B$ decays.
Physics at SuperKEKB

- New source of CP violation
- New source of flavor mixing
- LFV $\tau$ decays
- Precision test of KM scheme
- SUSY breaking mechanism
- Charm physics
- Super-high statistics measurements: $\alpha_s$, $\sin^2\theta_W$, etc.
Precision test of KM scheme

Result with 0.3 fb\(^{-1}\)

\[ \Delta \sin 2\phi_1 = 0.014 \]
\[ \Delta (f_B \sqrt{B_d}) = 0.005 \pm 0.015 \]
\[ \Delta |V_{ub}| = 4.4\% \]
\[ \Delta \phi_3 = 1.2^\circ \]

If tree-level and \(b \to d\) mixing processes give inconsistent results,

…indicates something new in
In general, new physics contains new sources of flavor mixing and CP violation.

- In SUSY models, for example, SUSY particles contribute to the $b \to s$ transition, and their CP phases change CPV observed in $B \to \phi K$, $\eta' K$ etc.

In general, if SUSY is present, the $s$-quark mixing matrix contains complex phases just as in the Kobayashi-Maskawa matrix.
A possible hint for NP: $b \rightarrow s \bar{q}q$

$$\frac{\sin(2\beta_{\text{eff}})}{\sin(2\phi_{1}\text{eff})}$$

Naïve average

$$\sin(2\phi_{1}\text{eff}) = 0.5 \pm 0.09$$

(2.6$\sigma$ from $\sin(2\phi_{1})$)
Sensitivity to new CP phases

Estimated error in the measurement of time dependent CP violation

Discovery region with 50 ab$^{-1}$
Search for new flavor mixing

: 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.

Theoretical predictions for $l^+l^-$ forward-backward charge asymmetry for SM and SUSY model with various parameter sets.

Possible observables:

- Ratio of branching fractions
- Branching fraction
- CP asymmetry
- $q^2$ distribution
- Isospin asymmetry
- Triple product correlation
- Forward backward asymmetry
- Forward backward CP asymmetry

The F/B asymmetry is a consequence of $\gamma-Z^0$ interference.
Sensitivity to new flavor mixing

Experimental result with 0.35 ab\(^{-1}\)

Belle, 2005

\[ (b) K^* l^+ l^- \text{ negative } A_F \]

\[ q^2 \text{ GeV}^2/c^2 \]

Standard model

Sensitivity at Super KEKB

\[ A_R \]

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

\[ \text{MC, 50 ab}^{-1} \]

- Zero-crossing \( q^2 \) for \( A_{FB} \) will be determined with 5% error with 50ab\(^{-1}\).

These patterns were excluded by recent data from Belle.
“$B$ meson beam” technique

B meson beam technique

$e^-$ $\gamma$ $e^+$
$B \rightarrow D \pi$

full reconstruction

0.2~0.3% for $B^+$

Application

$H^\pm$ search in $B \rightarrow \tau\nu$

$m_b \tan \beta + m_u \cot \beta$

$\bar{b}$ $m_\tau \tan \beta$

$H^+/W^+$

95.5%C.L. exclusion boundaries

Belle, 2006

5ab$^{-1}$ assumed

Application

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$m_b \tan \beta + m_u \cot \beta$

$\bar{b}$ $m_\tau \tan \beta$

$H^+/W^+$

95.5%C.L. exclusion boundaries

Belle, 2006

5ab$^{-1}$ assumed
Charm physics at $B$ factories

$D^0\bar{D}^0$ mixing may be observed at $B$ factories with higher $L$.

Belle, 2005, 400fb$^{-1}$

(0,0) CL 96.1%
Search for flavor-violating $\tau$ decay

**SUSY + Seesaw**
- Flavor violation by $\nu$-Yukawa coupling.
- Large LFV $\text{Br}(\tau \to \mu \gamma) = O(10^{-7}\sim 9)$

$$\text{BR}(\tau \to \mu \gamma) \sim 10^{-6} \times \left(\frac{m_{\tilde{L}}^2}{m_{\text{SUSY}}}\right)^{32} \left(\frac{1 \text{ TeV}}{\text{TeV}}\right)^4 \tan^2 \beta$$

Present Belle $\Rightarrow$ Super-KEKB

**Expected sensitivity at SuperKEKB**

$tan \beta = 30$, $A_0 = 0$, $\mu > 0$
Gaugino mass = 200GeV

SuperKEKB $10\text{ab}^{-1}$
Comparison with LHCb

<table>
<thead>
<tr>
<th>$e^+e^-$ is advantageous in…</th>
<th>LHCb is advantageous in…</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPV in $B \rightarrow \phi K_S, \eta' K_S, \ldots$</td>
<td>CPV in $B \rightarrow J/\psi K_S$</td>
</tr>
<tr>
<td>CPV in $B \rightarrow K_S \pi^0 \gamma$</td>
<td>Most of $B$ decays not including $\nu$ or $\gamma$</td>
</tr>
<tr>
<td>$B \rightarrow K\nu\nu, \tau\nu, D^{(*)}\tau\nu$</td>
<td>Time dependent measurements of $B_S$</td>
</tr>
<tr>
<td>Inclusive $b \rightarrow s \mu\mu$, see $\tau \rightarrow \mu\gamma$ and other LFV</td>
<td>$B_{(S,d)} \rightarrow \mu\mu$</td>
</tr>
<tr>
<td>$D^0 \bar{D}^0$ mixing</td>
<td>$B_C$ and bottomed baryons</td>
</tr>
</tbody>
</table>

These are complementary to each other!!
Why $\int L \, dt = 50ab^{-1}$ is a goal?

Most of the interesting measurements will be limited by unavoidable systematics when we reach $50ab^{-1}$.

<table>
<thead>
<tr>
<th>Obs.</th>
<th>$\delta_{\text{stat}}$ with 50ab$^{-1}$</th>
<th>$\delta_{\text{syst}}$ with 50ab$^{-1}$</th>
<th>Theory err.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sin 2\phi_1$</td>
<td>0.004</td>
<td>0.014</td>
<td>~0.01</td>
</tr>
<tr>
<td>$\phi_2$</td>
<td>1.2°</td>
<td>a few °</td>
<td></td>
</tr>
<tr>
<td>$\phi_3$</td>
<td>1.2°</td>
<td>O(1) °</td>
<td></td>
</tr>
<tr>
<td>$</td>
<td>V_{ub}</td>
<td>$</td>
<td>1%</td>
</tr>
<tr>
<td>$S_{\phi Ks}$</td>
<td>0.023</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>$A_{\phi Ks}$</td>
<td>0.016</td>
<td>0.018</td>
<td></td>
</tr>
<tr>
<td>$S_{\eta' Ks}$</td>
<td>0.013</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>$A_{\eta' Ks}$</td>
<td>0.009</td>
<td>0.017</td>
<td></td>
</tr>
<tr>
<td>DCPV in $b \to s \gamma$</td>
<td>0.003</td>
<td>0.002</td>
<td>0.003</td>
</tr>
</tbody>
</table>
\[ \int L \, dt = 50 \text{ab}^{-1} \]

- Takes 250 years with present KEKB
- 8.3 years with \( L_{\text{peak}} = 4 \times 10^{35} \) : baseline design of SuperKEKB

Great efforts are being made by the machine physicists at KEK.

- 3.3 years with \( L_{\text{peak}} = 1 \times 10^{36} \)
SuperKEKB

- **Asymmetric energy** $e^+e^-$ **collider at** $E_{CM}=m(\Upsilon(4S))$ **to be realized by upgrading the existing KEKB collider.**

- **Super-high luminosity** $\equiv 4\times10^{35}/\text{cm}^2/\text{sec} \rightarrow 5\times10^9 \text{ BB per yr.}$
  $\rightarrow 4\times10^9 \tau^+\tau^- \text{ per yr.}$

Higher beam current, more RF, smaller $\beta_y^*$ and crab crossing
$\rightarrow L = 4\times10^{35}/\text{cm}^2/\text{sec}$

http://belle.kek.jp/superb/loi
Proposed schedule

Integrated luminosity (ab⁻¹)

L_{\text{peak}} \approx 1.5 \times 10^{34} \quad 1.5 - 3 \times 10^{34} \quad \text{SuperKEKB} \quad \approx 4 \times 10^{35}

Belle is here.

0.58ab⁻¹

Crab cavity installation

2 yr shutdown for upgrade

5B BB and $\tau^+\tau^-$ every year

Belle is here.

0.58ab⁻¹


Calendar year
Super Belle

- Faster calorimeter with Wave sampling and pure CsI crystal
- Super particle identifier with precise Cherenkov device
- Background tolerant super small cell tracking detector
- Si vertex detector with high background tolerance
- New Dead time free readout and high speed computing systems
- KL/μ detection with scintillator and new generation photon sensors
Next three slides are from the report of “Future vision committee” lead by the previous KEK director, Yoji Totsuka, given to the new director, Atsuto Suzuki, WITHOUT giving any constraint to the new management.
Scenario Version 1

By previous KEK management
Scenario Version 2

By previous KEK management
Scenario Version 3

By previous KEK management
LCPAC recommendation

- LCPAC is a KEK’s advisory panel that gives recommendation on the $e^+e^-$ collider program at KEK.
- 2005 report says;

The main objective of SuperBelle is to elucidate the flavor structure of anticipated new physics at or beyond the TeV scale. We find the presented scientific goal exciting.

The Committee recommends to continue the accelerator and the detector R&D so that SuperKEKB can be proposed for construction when the time is ripe.
Internationalization

- “KEK + in-kind contribution from others” is a favorable scenario.
  - KEK cannot afford to pay for all, because it will also support J-PARC and ILC R&D.
  - Better chance to get early approval by the Japanese Government.

- We are open to any proposal.

- A possible way: form an international steering group of Super B factory without having a specific site or technology selected.
  - Have both SuperKEKB and Linear Super B (and others, if any) in the scope.
  - Make Super B factory more popular in the world-wide HEP community.
  - Submit joint proposals to the possible host labs.
The International Workshop on
B Factories and New Measurements
(BNM2006)

Sep. 13-14, 2006
KEK, Tsukuba, Japan

Topics
Upsilon(5s) and Other Energies
New Ideas on Upsilon(4s)
SuperKEKB Physics
New Detectors

Local Organizing Committee
S. Hashimoto (KEK),
M. Hazumi (KEK, Chik),
H. Béno (ITP),
K. Kinoshita (Cincinnati),
Y. Okada (KEK),
O. Tajima (KEK)
KEKB/Belle has been running very successfully, and brought important scientific achievements together with BaBar.

Next generation $e^+e^- B$ factory with $L>>10^{35}$ will be very useful to study the new sources of flavor mixing and CP violation.

SuperKEKB upgrade has been proposed

- Why? – Search for new sources of flavor mixing and CP violation
- How? – Increase $N_B$, decrease $\beta_\gamma^*$, and crab crossing: $L=4\times10^{35}/cm^2/s$
- What? – New beam pipe, crab cavity, new injector with damping ring. Belle will also be upgraded assuming DC is usable.
- Who? – KEKB/Belle is ready to serve as a core of the project, but it is open.
- Where? – Upgrade existing KEKB.
- When? – JFY2009 and 2010
- How much? – up to US$400M, depending on what to be upgraded.

Internationalization will be necessary for any Super B Factory to be realized.