News on SuperKEKB Physics Reach

Masashi Hazumi (KEK)
for
SuperKEKB physics study group

CERN Flavour Workshop
Oct. 9, 2006
Recap: SuperKEKB overview

- Super-high luminosity \( \equiv 8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1} \)

50 \(\times\) present world record (recorded at KEKB)

- Natural extension of KEKB
- \(8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}\) with technologies proven at KEKB, together with a few modifications

- Letter of Intent (LoI) in 2004
  - 276 authors from 61 institutions
  - available at http://belle.kek.jp/superb/loi
  - “Physics at Super B Factory” hep-ex/0406071

- HEP community in Japan is now discussing the Grand Lepton Collider plan to accommodate both SuperKEKB and ILC.
Changes since SuperKEKB LoI

• New results from Belle/BaBar with improved analyses
  – Better background rejection lead to evidence for $B \rightarrow \tau \nu$
  – Time-dependent CP violation meas. also improved
  – Isospin analysis for $\phi_2$ proven with $\pi \pi, \rho \pi, \rho \rho$

• New results from other experiments
  – $B_s$ mixing from CDF/D0

• Progress in theory, proposals for new measurements

Need to update physics studies done for LoI. Need to include new studies.

Workshop held at KEK in September. Interim reports given.
BNM2006 (B Factories and New Measurements)
http://www-conf.kek.jp/bnm/2006/

More than 100 participants: Many new ideas proposed. Very fruitful!
New results (not in LoI)

- **Modes with neutrinos**
  - $B \rightarrow \mu\nu$ ($1\,\nu$)
  - $B \rightarrow \tau\nu$ ($>1\,\nu$)

- **New ideas**
  - Use of conversion photons
    - $S(B^0 \rightarrow \pi^0\pi^0)$ measurements with vertices from $\gamma \rightarrow e\bar{e}$
    - $B \rightarrow K^*\gamma$ with $\gamma \rightarrow e\bar{e}$
  - Direct CP violation in $B^0 \rightarrow K_S\pi^0$ vs. $B \rightarrow K\pi$ sum rule: $\Delta A(K_S\pi^0)$
  - Upsilon(5S) and other energies
  - Ambitious detectors (not covered in this talk)

- **Estimations based on new measurements at Belle**
  - $\text{Br}(B \rightarrow X_d\gamma)$
  - $S(B^0 \rightarrow \rho^0\gamma)$
  - TPC (triple product correlations) with $B \rightarrow VV$

- **Progress in theory side**
**B \to \mu \nu**

- Highly energetic muon
- Accompanied B reconstructed with the remaining particles (neutrino reconstruction technique)

- $\text{Br}(B \to \mu \nu)$ upper limit measurement:
  
  significance is about $1.3\sigma$ from the current Belle results (250fb$^{-1}$)

Assuming that significance depends on luminosity in the following plot

<table>
<thead>
<tr>
<th>sigma</th>
<th>Lum (ab$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3\sigma</td>
<td>1.3</td>
</tr>
<tr>
<td>5\sigma</td>
<td>3.7</td>
</tr>
</tbody>
</table>

Cf. $5\sigma @ 5.8$ab$^{-1}$

with SM branching ratio

\[ \leftrightarrow \] Hadronic-tagging:

Need 15ab$^{-1}$ for the $3\sigma$ sensitivity
$H^\pm$ constraints from $B \rightarrow \tau\nu$: SuperKEKB projections

\[ \beta(B \rightarrow \tau\nu) = \frac{G_F^2 m_B}{8\pi} m_T^2 \left(1 - \frac{m_T^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B \]

Use known $f_B$ and $|V_{ub}|$

Ratio to the SM BF.

\[ r_H = \left(1 - \frac{m_B^2}{m_H^2}\right) \tan^2 \beta \]

$50 \text{ ab}^{-1}$

$\Delta f_B(\text{LQCD}) = 5\%$

95.5\% C.L. exclusion regions

If $\Delta|V_{ub}| = 0$ \& $\Delta f_B = 0$
Constraints at Super-B (cont.)

Charged Higgs Mass Reach
(95.5%CL @ tanβ=30)

Only exp. error
(ΔV_{ub}=0%, Δf_{B}=0%)

ΔV_{ub}=2.5%, Δf_{B}=2.5%

ΔV_{ub}=5%, Δf_{B}=5%

Mass Reach (GeV)

Luminosity (ab^{-1})
Constraints at Super-B from $B \to D\tau\nu$

(no update from LoI yet)

$H^\pm$ search in $B \to D\tau\nu$

$m_b \tan \beta + m_c \cot \beta$

$\chi\rightarrow \tau^+\nu_{\tau}$

Similar to $B \to \tau\nu$

$5 \text{ ab}^{-1} \rightarrow M_H > \frac{M_W \tan \beta}{11}$

$50 \text{ ab}^{-1} \rightarrow M_H > \frac{M_W \tan \beta}{5}$
Full reconstruction modes

<table>
<thead>
<tr>
<th>Process</th>
<th>5σ</th>
<th>Sensitivity</th>
<th>Other Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B \rightarrow \tau \nu$</td>
<td></td>
<td></td>
<td>$10%$</td>
</tr>
<tr>
<td>$B \rightarrow \mu \nu$</td>
<td></td>
<td>$5\sigma@3.7\text{ab}^{-1}$</td>
<td>with present central value</td>
</tr>
<tr>
<td>$B \rightarrow K^+\nu\nu$</td>
<td></td>
<td>$5\sigma@5.8\text{ab}^{-1}$</td>
<td>with SM branching ratio</td>
</tr>
<tr>
<td>$B \rightarrow K^*\nu\nu$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$B \rightarrow K_s\nu\nu$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$B \rightarrow D\tau\nu$</td>
<td></td>
<td></td>
<td>$M(\text{H}^+) &gt; 400\text{GeV} (2\sigma)$ at $\tan\beta = 30$</td>
</tr>
</tbody>
</table>

Very important progress on these theoretically clean modes!

Need to work on $B \rightarrow K^*\nu\nu$, $K_s\nu\nu$

Need to work on $B_d \rightarrow \mu^+\mu^-$, $e^+e^-$

New!

Preliminary
Isospin analysis w/ or w/o $S_{00}$
(S term for $B^0 \rightarrow \pi^0\pi^0$)

- Reconstruction efficiency w/ vertexing: 1.3%
- How many signal events w/ 50/ab data?: 850 events.
- Toy MC
  - # of signal = 850
  - three cases: signal fraction = 100%, 50%, 25%.
  - resolution function obtained from Geant MC
  - tagging efficiency 30%.
- RMS of fitted $S_{00}$
  - $\delta S_{00} = 0.18$ (for sig. frac. = 100%), 0.26 (50%) and 0.36 (25%)

Cf. Larger vtx detector $\rightarrow$ larger conversion eff
Detector optimization $\rightarrow$ large improvement

Ishino, Hazumi, Yoshikawa
Photon polarization in $B \to K^*\gamma$ with $\gamma \to e^+e^-$

- $B \to K^*\gamma$ with $\gamma \to e^+e^-$ in the detector could be used to measure the left- and non-SM right-handed components ($A_L$ and $A_R$) (Grossman-Pirjol JHEP 0006,029(2000))

- If $A_R \neq 0$, phi modulation in the form:
  
  $$1 + \xi(E_e, q^2) \frac{|A_R| |A_L|}{|A_R|^2 + |A_L|^2} \cos(2\phi + \delta)$$

  $$\xi: \text{efficiency factor average } \xi \sim 0.3$$

- Very clear signal
- Signal should be already visible with current data

- A full-MC test for 5 ab$^{-1}$ (with loosened cuts for background)
- Fit with $N(1 + A \cos(2\phi + \delta)) \Rightarrow A = 0.085 \pm 0.067$

- Given that $\xi \sim 0.3$, $A_R \sim A_L$ is needed for $> 3\sigma$ at 5 ab$^{-1}$, and
  - Need to evaluate $\xi$ in a boosted CM system
  - Need to evaluate detector effects/bias
  - Need to separate conversion and low-$q^2$ $B \to Ke^+e^-$
\[ \Delta A(B^0 \rightarrow K_S \pi^0) \]

Sum rule

\[ A_{CP}(K^+ \pi^-) + A_{CP}(K^0 \pi^+) \approx A_{CP}(K^+ \pi^0) + A_{CP}(K^0 \pi^0) \]


- Diff. between experiment and sum rule
  - \( \Delta A_{CP}(K_S \pi^0) = 0.10 \) (Belle only), 0.03 (HFAG Avg.)
- Uncertainty on the sum rule
  - \( \delta A \approx \pm 0.002 \) @5/ab, \( \approx \pm 0.001 \) @50/ab
- Uncertainty on the experimental measurement
  - \( \delta A \approx \pm 0.072 \) @5/ab, \( \approx \pm 0.050 \) @50/ab

Preliminary

can be improved by optimizing flavor tagging
Upsilon(5S) and other energies

- **Upsilon(5S)**
  - Belle results with engineering runs (1.86/fb) at ICHEP2006
  - Belle recorded 21.7/fb (June 9-31, 2006). Results expected in the winter conferences
    - Branching fractions for semileptonic Bs decays: 5~10% accuracy
    - Br[Bs → Ds(*)+Ds(*)-]: ~30% accuracy
    - ~100/fb to reach SM Br for Bs → γγ
    - Need more studies on ΔΓ/Γ with Bs → sensitive to cosine of a new phase

- **Upsilon(3S):** best place to search for light dark matter candidates
- **Upsilon(1S-4S):** test of lepton universality

O(1) month running at SuperKEKB enough for ~1/ab

Drutskoi, Pierini

ΔΓ_{CP}^{s} \approx \frac{Bf(B_s \rightarrow D_s^{(*)} + D_s^{(*)})}{Γ_s} \approx \frac{1 - Bf(B_s \rightarrow D_s^{(*)} + D_s^{(*)})}{2}
$\mathbf{B \to X_d \gamma}$ at $5/ab$

- **A fit result:**
  \[ Y = 6432 \pm 298 \pm 800 \]

- **Error sources:**
  - Stat.: 5%
  - Fit.: 13%
  - Model: 10%
  - Total: 17%

$B \to X_d \gamma$ seems to be possible with $5 \text{ ab}^{-1}$!
(still challenging, systematic error could be quite different in reality)
$S(B^0 \rightarrow \rho^0\gamma)$

- Toy MC study based on Belle’s and SM-like $\bar{B}^0 \rightarrow \rho^0\gamma$ rate

- Vertexing efficiency
  $\sim 87\%$ (a la $\phi K_S^0$)

- All background PDF
  $B \rightarrow K^*\gamma, X_s\gamma, \rho\pi^0, \text{other } B$ decays, continuum

- Background $\Delta t$ PDF from $K_S^0\pi^0\gamma$ analysis

Need $50 \text{ ab}^{-1}$ for $\sim 10\%$ error
And many other sensitivity numbers → how to use them for new physics studies?

- Scaling from Belle or BaBar results.
- $K^{*0}K^{*0}$ is estimated with $Bf \sim 0.5 \times 10^{-6}$ and an efficiency of 3.6%.
- An 1% systematic uncertainty limitation is assumed (dominated by the uncertainty on detector acceptance).
### $b \rightarrow s/d$ Precision Summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Updated</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_K$</td>
<td>0.07</td>
<td>0.02</td>
</tr>
<tr>
<td>$A_{CP}(b\rightarrow s\gamma)$</td>
<td>0.01</td>
<td>0.005</td>
</tr>
<tr>
<td>$A_9$</td>
<td>11%</td>
<td>4%</td>
</tr>
<tr>
<td>$A_{10}$</td>
<td>13%</td>
<td>4%</td>
</tr>
<tr>
<td>$B \rightarrow X_d\gamma$</td>
<td>$7.5\sigma$</td>
<td>Preliminary</td>
</tr>
<tr>
<td>$S(Ks\pi0\gamma)$</td>
<td>0.1</td>
<td>0.03</td>
</tr>
<tr>
<td>$S(\rho0\gamma)$</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>$A_R$ w/ $\gamma$pol</td>
<td>3$\sigma$ if $A_R$~$A_L$</td>
<td></td>
</tr>
<tr>
<td>$S(KsKsKs)$</td>
<td>0.105</td>
<td>0.037</td>
</tr>
<tr>
<td>$S(\phi K0)$</td>
<td>0.073</td>
<td>0.029</td>
</tr>
<tr>
<td>$S(\eta'K0)$</td>
<td>0.038</td>
<td>0.020</td>
</tr>
<tr>
<td>$\Delta A(Ks\pi0)$</td>
<td>0.072</td>
<td>0.050</td>
</tr>
</tbody>
</table>

- **New!**
- **Updated**
- **No Update**

**Int. Lumi (ab-1)**
CKM fit at SuperKEKB

Int. Lumi (ab-1)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi_1$</td>
<td>0.016</td>
<td></td>
</tr>
<tr>
<td>$\phi_2$</td>
<td></td>
<td>2deg*</td>
</tr>
<tr>
<td>$\phi_3$</td>
<td></td>
<td>&lt;2deg**</td>
</tr>
<tr>
<td>Vub(inclsv)</td>
<td>6.6%</td>
<td></td>
</tr>
<tr>
<td>Vub(exclsv)</td>
<td>~12%</td>
<td></td>
</tr>
</tbody>
</table>

* $\phi_2$ theory error will be an issue.

** $\phi_3$ assumes ~10/fb $\psi(3770) \rightarrow DD$ for theory-uncertainty-free measurements

Itoh, Krokovny, Kusaka, Limosani
τ LFV: Estimated ULs at 5ab$^{-1}$

- PDG2006
- Belle
- Babar

Based on eff. and $N_{BG}$ of most sensitive analysis

Estimated upper limit range of $Br$
SuperKEKB projections for $\tau \rightarrow \mu \gamma$

- ToyMC estimation for $\tau \rightarrow \mu \gamma$
- $1/\sqrt{n}$
- $1/n$
- Upper limit (90% C.L.)

- MSSM+Seesaw
- $535 \text{ fb}^{-1}$
- $5 \text{ ab}^{-1}$

- ~proportional to $\sqrt{N}$
- with 3ab$^{-1}$ data sample
- UL will reach $9 \times 10^{-9}$.
Theory: Super KEKB LoI update

- Update the SUSY case study as an example of new physics models, including the Bs mixing.

- Add new measurements
  e.g. Triple product correlations.
  New ideas on right-handed current search in radiative B decays.
  new idea also covered by A.Soni’s talk today

- More discussions on B leptonic decays, semi-tauonic decays, and tau LFV decays.

- Add theoretical motivations and phenomenological introduction to Bs physics.
Schedule

• **BNM2006-II**
  - December 18, 19 in Nara
    • after CKM2006 in Nagoya (Dec.12-16)
    - Finalize sensitivity studies

• **Revised SuperKEKB physics book by the end of 2006**
  - Aim for publication

• **Include the results in the yellow report**
Backup Slides
Three factors to determine luminosity:

Stored current:
1.36/1.75 A (KEKB)
→ 4.1/9.4 A (SuperKEKB)

Beam–beam parameter:
0.059 (KEKB)
→ >0.24 (SuperKEKB)

Luminosity:
0.16 ×10^{35} \text{ cm}^{-2}\text{s}^{-1} (KEKB)
8×10^{35} \text{ cm}^{-2}\text{s}^{-1} (SuperKEKB)

Vertical $\beta$ at the IP:
6.5/5.9 mm (KEKB)
→ 3.0/3.0 mm (SuperKEKB)
Bkg & TRG rate in future

<table>
<thead>
<tr>
<th></th>
<th>KEKB</th>
<th>SuperB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminosity</td>
<td>~1</td>
<td>80</td>
</tr>
<tr>
<td>(10^{34}\text{cm}^{-2}\text{sec}^{-1})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HER curr. (A)</td>
<td>1.2</td>
<td>4.1</td>
</tr>
<tr>
<td>LER curr. (A)</td>
<td>1.6</td>
<td>9.4</td>
</tr>
<tr>
<td>vacuum (10^{-7}\text{Pa})</td>
<td>~1.5</td>
<td>5</td>
</tr>
<tr>
<td>Bkg increase</td>
<td>-</td>
<td>x 20</td>
</tr>
<tr>
<td>TRG rate (kHz)</td>
<td>0.4</td>
<td>14</td>
</tr>
<tr>
<td>phys. origin</td>
<td>0.2</td>
<td>10</td>
</tr>
<tr>
<td>Bkg origin</td>
<td>0.2</td>
<td>4</td>
</tr>
</tbody>
</table>

**Synchrotron radiation**
- Beam-gas scattering (inc. intra-beam scattering)
- Radiative Bhabha
SuperBelle detector

SC solenoid 1.5T

CsI(Tl) 16$X_0$ → pure CsI (endcap)

Aerogel Cherenkov counter + TOF counter → “TOP” + RICH

μ / $K_L$ detection 14/15 lyr. RPC+Fe → tile scintillator

Tracking + $dE/dx$ small cell + He/C$_2$H$_6$ → remove inner lyr. Use fast gas

Si vtx. det.

4 lyr. DSSD → 2 pixel/striplet lyr.
+ 4 lyr. DSSD

New readout and computing systems

In general, requirements less severe than those for LHC
Recap: Sensitivities (SuperKEKB LoI)

SuperKEKB 5ab\(^{-1}\)  

SuperKEKB at 5 ab\(^{-1}\)  

SuperKEKB at 50 ab\(^{-1}\)  

LHCb 2fb\(^{-1}\)  

LHCb (0.002 ab\(^{-1}\))

- \(\Delta S(\phi K_s)\)
- \(\Delta S(K^* K K_s)\)
- \(\Delta S(\eta' K_s)\)
- \(\Delta S(K_s K_s K_s)\)
- \(\Delta S(\pi^0 K_s)\)
- \(\sin 2\chi (B_s \rightarrow J/\psi \phi)\)
- \(S(K^0\gamma)\)
- \(Br(B \rightarrow X_s \gamma)\)
- \(A_{CP}(B \rightarrow X_s \gamma)\)
- \(C_9 w/ A_{FB}(K^+ \psi)\)
- \(C_{10} w/ A_{FB}(K^+ \psi)\)
- \(Br(B_s \rightarrow \mu^+ \mu^-)\)
- \(Br(B^+ \rightarrow K^+ \nu \nu)\)
- \(Br(B^{*} \rightarrow K^{*} \nu \nu)\)
- \(Br(B^+ \rightarrow D \tau \nu)\)
- \(Br(B^{*} \rightarrow D \tau \nu)\)
- \(\sin 2\phi_1\)
- \(\phi_2(\pi \pi \text{ isospin})\)
- \(\phi_2(\rho \pi)\)
- \(\phi_2(D K^{(*)})\)
- \(\phi_3(B_s \rightarrow K K)\)
- \(\phi_3(B_s \rightarrow D s K)\)
- \(|V_{ub}|\)
Major Achievements Expected at SuperKEKB

Case 1: All Consistent with Kobayashi-Maskawa Theory

- Discovery of $B J K \nu \nu$
- CKM Angle Measurements with 1 degree precision
- Discovery of $B \rightarrow K \nu \nu$
- Discovery of New Subatomic Particles
- $\sin^2\theta_W$ with $O(10^{-4})$ precision
- $|V_{ub}|$ with 5% Precision
- Discovery of $B \rightarrow D \tau \nu$
- Discovery of $B \rightarrow \mu \nu$
- Discovery of CP Violation in Charged $B$ Decays
- Discovery of Direct CP Violation in $B^0 \rightarrow K \pi$ Decays (2005)
- Discovery of CP Violation in Neutral $B$ Meson System (2001)

“Discovery” with significance > 5σ
**Major Achievements Expected at SuperKEKB**

- Discovery of $B_J^K\nu\nu$
- Discovery of $B_J^D\tau\nu$
- Discovery of $B_J^\mu\nu$
- CKM Angle Measurements with 1 degree precision
- Discovery of CP Violation in Charged $B$ DECAYS
- Discovery of Direct CP Violation in $B_0^0J^K\pi$ Decays (2005)
- Discovery of CP Violation in Neutral $B$ Meson System (2001)
- Discovery of CP Violation in Charged $B$ DECAYS
- Discovery of Lepton Flavor Violation in $\tau \rightarrow \mu \gamma$ Decays
- Discovery of New Right-Handed Current in $b \rightarrow s$ Transitions
- Discovery of New CP Violation in $B_0^0 \rightarrow \phi K^0$ DECAYS
- Discovery of CP Violation in Charged $B$ DECAYS
- “Discovery” with significance $> 5\sigma$
- # SUSY GUT with gluino mass = 600GeV, $\tan\beta = 30$
Which is the correct description of Nature?
No Super B factory, no answer.
Physics at SuperKEKB is “DNA Identification of New Physics”.

© D. Hitlin
The future plan of Japanese Higher Energy Physics Community is under discussion and not yet concluded. This is not more than a material for the discussion.

「大レプトン計画」
Grand Lepton Collider Project

K. Oide for HEC
Aug. 17 & Sep. 9, 2006
We will do everything: ILC, SuperKEKB, J-Parc.

<table>
<thead>
<tr>
<th>Year</th>
<th>ILC</th>
<th>SuperKEKB</th>
<th>J-Parc</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>R&amp;D II</td>
<td>Constr.</td>
<td>Experiment</td>
</tr>
<tr>
<td>2015</td>
<td>Construction</td>
<td></td>
<td>Experiment</td>
</tr>
<tr>
<td>2020</td>
<td>Exp.</td>
<td></td>
<td>Phase-II</td>
</tr>
</tbody>
</table>

- All members of KEK-ACCL will have both duties for ILC and SuperKEKB.
- The weight between SuperKEKB and ILC is subject to change, depending on the readiness of ILC.
- The individual role and weight in the two projects should be flexibly managed by considering time, speciality, and occasion.
• In the 2010s decade, while producing physics by SuperKEKB, utilize KEKB accelerator’s material and human resources to the R&D of ILC.

• Upgrade KEKB to SuperKEKB, and do experiment.

• R&D of ILC for industrialization and construction.

• Items of utilization of KEKB for ILC R&D:
  - positron sources, flux concentrator
  - orbit and emittance control in linac
  - low-emittance operation of KEKB-LER
  - electron cloud, test of beam pipes and coatings
  - effect of wigglers
  - development of ring rf system with ILC spec, development of ring klystrons
  - next generation of bunch-by-bunch feedback, ring BPM
  - Detector Components
• Basic structure remains the same.
• Some more descriptions about why a Super B factory is essentially important.
  – TeV new physics introduces new flavor mixing and CP violation.
    • Mixing is often large as history tells.
  – Measurements needed to uncover the flavor structure.
  – 50/ab sufficient to study couplings of TeV particles
    • 30/fb for observation of CP violation from top-quark coupling
    • LHC energy 7 times higher than Tevatron $\Rightarrow$ New physics effect: $1/7^2 \sim 1/7$
    • Sufficient statistics: $30/\text{fb} \times [7^2 \sim (7^2)^2 ] \Rightarrow 1.5/\text{ab} \sim 75/\text{ab}$
  – Theoretically clean measurements with experimentally clean environments; some key measurements carried out only at a Super B.