Prospects for upgrades of KEKB and Belle

Belle and beyond: physics, collider, detector

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Belle Collaboration
Belle (1999-present)

- RICH physics in the Upsilon region

Headliners
- CKM, including $\sin 2\varphi_1$, constraints on $\varphi_2$, $\varphi_3$
- new charmonia, charmonium-like states in continuum, ISR, $D_{sJ}$, B decays
- $D^0$ mixing
- probes of New Physics

+ many more measurements on B, charm, tau, 2-photon, $\Upsilon(4S)$, $\Upsilon(10860)$, $B_s$, $\Upsilon(3S)$, $\Upsilon(1S)$, ...

Addressing
- CP, CKM, QCD, HQ spectroscopy, LFV, NP, Dark Matter, ...

265 journal articles published/submitted

http://belle.kek.jp/bdocs/b_journal.html
Why continue in flavor physics?

- CKM: highly constrained pattern of CC couplings with CP violation manifested in diverse processes in B decay 
  -> many measurements, (over)constrain CKM
- statistics limited on $\rho^0\rho^0(\varphi_2)$, Dalitz analyses ($\varphi_3$), $b\rightarrow d\gamma$, $\tau\rightarrow \mu \gamma$, ...
- SM extensions likely to have new sources of CPV & flavor couplings 
  -> precision CKM as window to New Physics
- in 1.4 ab$^{-1}$ at Belle+Babar: hints of New Physics?
  -> to open the window, $X10^2$ luminosity at B-factory 
    pro’s vis-a-vis LHCb: $\gamma$, $K_L$ detection; hermeticity -> neutrinos

- CP asymmetry in $b\rightarrow s$ penguin -> non-SM contributions
- Lepton universality $B\rightarrow \tau \nu$, $B\rightarrow D^{(*)} \tau \nu$
- Right-handed currents CP asymmetry of $B\rightarrow \{s\} \gamma$
- Inclusive $b\rightarrow s \gamma$, $b\rightarrow d \gamma$, $B\rightarrow s l^+ l^-$
- CP asymmetry in D mixing -> NP

... + many B-factory measurements are not yet systematics limited
CP asymmetry in $B \to s\bar{s}\bar{s}$: $\sin 2\varphi_1$ in SM

for $B \to J/\psi K_s$

- tree (real $V_{ij}$) $\propto V_{cb}^*V_{cs}$
- mixing + tree $\propto V_{tb}^2V_{td}^2V_{cb}V_{cs}^*$

Phase of mixing $(V_{tb}^*V_{td}) = 2\varphi_1$, $V_{cb}V_{cs}$ real $\to$ asym $\sim \sin 2\varphi_1$

for $b \to s\bar{s}\bar{s}$

- similarly, penguin & mixing+penguin
  - due to loop cancellation, large $m_t \to \propto V_{tb}V_{ts}$
    - real $\to$ asym $\sim \sin 2\varphi_1$
  - NP w complex phase $\varphi_{\text{new}} \to$ asym $\sim \sin (2\varphi_1 \pm 2\varphi_{\text{new}})$
Average “sin2\(\varphi_1\)” from \(b\rightarrow s\) penguins

Naïve World Average

\[ \sin^2\varphi_1(b\rightarrow sq\bar{q}) = 0.56 \pm 0.05 \]

Compare to \(cc\bar{s}\):

\[ \sin^2\varphi_1(b\rightarrow ccs) = 0.680 \pm 0.025 \]

\[ \text{CL} = 0.03 \ (2.2\sigma) \]

- statistics?
- experimental systematics?
- theory corrections?
- new physics?
CP asymmetry in $b \to s$: SuperKEKB sensitivity

SM prediction

some of recent QCDF estimates

\[
\sin 2\beta^*_t - \sin 2\beta
\]

\[
\begin{align*}
\phi K'_S \\
\eta' K'_S \\
x K'_S \\
\phi K_S \\
K K K_S \\
3K_S
\end{align*}
\]

$B \to \phi K^0, \eta' K^0, KsKsKs$ projection for SuperKEKB

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

Belle (July 2006, 492 fb$^{-1}$)
SuperKEKB (50 ab$^{-1}$)

$\Delta S(K^0_{S}K^0_{S})$
$\Delta S(\eta' K^0)$
$\Delta S(K^0)$
$B^+ \rightarrow \tau^+ \nu_\tau$ : constraints on charged Higgs

\[ \mathcal{B}(B \rightarrow \tau \nu) = \mathcal{B}(B \rightarrow \tau \nu)_{\text{SM}} \times r_H \]

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

(Belle) 0.41 ab$^{-1}$

\[ \mathcal{B}(B \rightarrow \tau \nu) = (1.8 \pm 0.5 \pm 0.5) \times 10^{-4} \]

PRL 97, 251802 (2006)

(extrapolation) 50 ab$^{-1}$

{WS Hou, PRD 48, 2342 (1993)}
Lepton universality: $B \rightarrow \mu \nu$

SM:
$B(B \rightarrow \tau \nu) = 1.6 \times 10^{-4}$
$\boxed{B(B \rightarrow \mu \nu) = 7.1 \times 10^{-7}}$
$B(B \rightarrow e \nu) = 1.7 \times 10^{-11}$

deviations from SM sensitive to NP

expect observation within few $ab^{-1}$
$B \to D^{(*)} \tau \nu$

- Lepton universality via semileptonic decays

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

- Ratio ($\tau/\mu$) is sensitive to charged Higgs (similar to $B \to \tau \nu$)

$B(B^0 \to D^{*-} \tau \nu) = (2.0 \pm 0.4 \pm 0.4)\%$

[PRL 99, 191807 (2007)]

$B \to \tau X$ decays probe NP in different ways:

- $B \to \tau \nu$: H-b-u vertex
- $B \to D \tau \nu$: H-b-c vertex
Right-handed currents

Sizable CP asymmetry expected in $B^0 \to X_s \gamma$
if NP includes right-handed current

$CP$ asymmetry in $B \to K_S \pi^0 \gamma$

PRD 74, 111104(R) (2006)
D mixing/CP violation

For 75 ab$^{-1}$

- $x = 0.8$ with $>4\sigma$ significance on $x$

- $y = 0.8$ with $>5\sigma$ significance on $y$

$|q/p| = 0.9$

$\sim 4\sigma$ significance on $1 - |q/p|$
KEKB Upgrade plan

- upgrade existing KEKB collider
- Final goal: $L = 8 \times 10^{35} / \text{cm}^2 / \text{sec}$ and $\int L \, dt = 50 \, \text{ab}^{-1}$

"adiabatic" - test/install in existing machine
KEKB track record (although past performance does not guarantee future results...)

- KEKB/Belle: ~842/fb (6/08)
- KEKB + PEP-II: ~1.4 billion $B\bar{B}$ pairs
- PEP-II/BaBar: ~553/fb

$L_{\text{peak}} = 1.7 \times 10^{34} \text{ cm}^2/\text{sec (design=1.0)}$
Luminosity Projection (preliminary)

operation time: 200 days/year

Integrate luminosity (ab^-1)

Peak luminosity (cm^-2 s^-1)

Peak current (A)

Year

2010 2015 2020 2025

Target for roadmap

KEK roadmap

Damping Ring

RF upgrade

3 years shutdown

Target for roadmap
Crab cavities: as of June 08, $L_{\text{max}} = 1.61 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$

A number of measurements indicate effective head-on collision.

The vertical tune shift became higher than 0.088. Before crab, it was 0.055.

The specific luminosity / bunch was improved more than the geometrical gain.

Need more time to achieve the goal (X2 specific luminosity).
Super KEKB: detector requirements and strategy

**Issues**
- Radiation damage
- Occupancy
- Fake hits, pile-up
- Event rate

*Background projection (preliminary)*

Relative background vs. Year

- SVD
- CDC
- PID
- ECL
- KLM (FWD)

Legend:
- Beam Gas + Touschek
- Synchrotron Radiation
- Luminosity term

Begins with 7~10x
~5x in the first few years
20x at full spec
(the detector temporarily known as) sBelle

Faster calorimeter with waveform sampling and pure CsI (endcap)

New particle identifier with precise Cherenkov device:
(i)TOP or fDIRC.
Endcap: Aerogel RICH

KL/µ detection with scintillator and next generation photon sensors

New dead time free pipelined readout and high speed computing systems

Si vertex detector with high background tolerance ((1)faster readout then (2)pixels)

Background tolerant super small cell tracking detector

New particle identifier with precise Cherenkov device:
(i)TOP or fDIRC.
Endcap: Aerogel RICH

[upgrade Belle to operate w 20X background, 50X event rate]
Silicon inner tracker

- improve vertexing -> thin innermost 2 layers, reduce inner radius
- improve $K_S$ acceptance -> increase outer radius
- background/occupancy -> striplets, pixels, pipelined readout

<table>
<thead>
<tr>
<th></th>
<th>Belle</th>
<th>sBelle ($t=0$)</th>
<th>sBelle ($t&gt;&gt;0$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector type</td>
<td>4 X DSSD</td>
<td>4X DSSD + 2 X DSSD (short strips)</td>
<td>2 X pixel + 4 X DSSD</td>
</tr>
<tr>
<td>Inner radius</td>
<td>15 mm</td>
<td>15 mm</td>
<td>10 mm</td>
</tr>
<tr>
<td>Outer radius</td>
<td>70 mm</td>
<td>120 mm</td>
<td>120 mm</td>
</tr>
<tr>
<td>DSSD readout</td>
<td>Hold/readout</td>
<td>pipelined</td>
<td>pipelined</td>
</tr>
<tr>
<td>Readout time</td>
<td>800 ns</td>
<td>50 ns</td>
<td>50 ns</td>
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</tbody>
</table>
Current concepts

**Drift chamber**
- improve momentum resolution -> increase outer radius
- improve dE/dx -> longer radial path
- background/occupancy -> smaller cells

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<thead>
<tr>
<th></th>
<th>Belle</th>
<th>sBelle (t&gt;0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner radius</td>
<td>77 mm</td>
<td>160 mm</td>
</tr>
<tr>
<td>Outer radius</td>
<td>880 mm</td>
<td>1140 mm</td>
</tr>
<tr>
<td>Inner layer cell size</td>
<td>12 mm</td>
<td>8 mm</td>
</tr>
<tr>
<td># sense wires</td>
<td>8400</td>
<td>15140</td>
</tr>
</tbody>
</table>
Current concepts

Particle ID
- improve $K/\pi$ for $b\rightarrow s$ vs $b\rightarrow d$, etc.
- add endcap PID
- reduce material in front of calorimeter

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<tr>
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<th>sBelle ($t&gt;0$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrel</td>
<td>Aerogel TOF</td>
<td>Cerenkov time-of-propagation (TOP)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[imaging TOP]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[focusing DIRC]</td>
</tr>
<tr>
<td>Endcap</td>
<td>none</td>
<td>Aerogel RICH</td>
</tr>
</tbody>
</table>
Current concepts

Electromagnetic calorimeter

- reduce background without loss of resolution

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<th>sBelle ($t&gt;0$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Barrel</strong></td>
<td>CsI (Tl)</td>
<td>CsI(Tl) + waveform sampling/fitting</td>
</tr>
<tr>
<td><strong>Endcap</strong></td>
<td>CsI(Tl) 1000 ns</td>
<td>Pure CsI 30 ns PMT + waveform sampling/fitting</td>
</tr>
<tr>
<td><strong>Rise time</strong></td>
<td>Si photodiode</td>
<td></td>
</tr>
<tr>
<td><strong>Photodetector</strong></td>
<td></td>
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</tr>
</tbody>
</table>
Current concepts

**$K_L$ / muon detector**
- reduce background in endcap

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<tr>
<th></th>
<th>Belle</th>
<th>sBelle ($t&gt;0$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrel</td>
<td>Glass RPC, streamer mode</td>
<td>Same RPC (avalanche mode?)</td>
</tr>
<tr>
<td>Endcap</td>
<td>Glass RPC, streamer mode</td>
<td>Plastic scintillator x-y strips</td>
</tr>
</tbody>
</table>
Placement of KEKB upgrade on roadmap is significant

- 3-year KEKB upgrade (’09-’11) with constant annual budget (KEKB operations → construction)
- Staging RF cavities etc, initial L ~ $2 \times 10^{35}$ cm$^{-2}$s$^{-1}$
- Funding: KEK management in discussions w agency (MEXT)
International group for sBelle

- New experimental group being formed (not an extension of present Belle collaboration): name TBD
- New participants are welcome, will have equal opportunities to work on detector construction and physics

Interim Steering Committee:
Hiroaki Aihara (Tokyo/IPMU), Alex Bondar (BINP), Tom Browder (Hawaii), Paoti Chang (NTU), Toru Iijima (Nagoya), Peter Krizan (Chair, Ljubljana), Thomas Muller (Karlsruhe), Henryk Palka (Crakow), Christoph Schwanda (Vienna), Martin Sevior (Melbourne), Eunil Won (Korea), Changzheng Yuan (IHEP, China), Yutaka Ushiroda, Yoshi Sakai (KEK), Masa Yamauchi (KEK)
Summary

• B-factories 1999-2009, >1.4x10^9 B pairs:
  established CKM as source of CP asymmetry in weak interaction
  multiple measurements on CKM with increasing precision:
    \( \phi_1, \phi_2, \phi_3, |V_{ub}|, \)
    -> probe New Physics:
  discoveries: D mixing, new hadronic states
  studies of tau
  a few unresolved effects: K\pi CP asymmetry, imperfect CKM fit

• \( \sim 10^2 \times \) luminosity will probe significantly into >1 TeV mass scale
  precision CKM, CP, lepton universality, LFV
• KEKB upgrade for L=2-8 x 10^{35} included in KEKB Roadmap
• KEKB/Belle upgrade plans well underway
  new international collaboration forming