B Factories: Status and Prospects

Masashi Hazumi
(KEK)

March 28, 2007
Flavor in the era of the LHC
CERN

CKM: Cabibbo-Kobayashi-Maskawa
CPV: CP Violation
It seems all the important results from B factories have already been shown and discussed at this workshop in the last two days. What should I talk about?

CKM: Cabibbo-Kobayashi-Maskawa
CPV: CP Violation

Masashi Hazumi
(KEK)

March 28, 2007
Flavor in the era of the LHC
CERN
Outline

• Introduction
• CPV and CKM
• New physics searches
• Future prospects

All introductory slides are put in the backup part.
Integrated luminosity

~1 Billion $BB$ pairs

Triumph in accelerator science!

KEKB

PEP-II

KEKB + PEP-II

KEKB for Belle

PEP-II for BaBar

~710/fb (Jan 07)

~400/fb

~1 Billion $BB$ pairs

Triumph in accelerator science!

Integrated luminosity (log)

1100/fb !!
Achievements at B factories

- Evidence for $D^0$ mixing
- Observation of direct CP violation in $B \rightarrow \pi^+\pi^-$
- Observation of $b \rightarrow d\gamma$
- Evidence for direct CPV in $B \rightarrow K^+\pi^-$
- Discovery of $X(3872)$
- Hint at new physics: CPV in $B \rightarrow \phi K_s$
- Observation of $B \rightarrow K^{(*)}ll$
- Observation of CPV in B meson system

Exciting results every year!
CPV and CKM
Discovery of CPV in the B meson system (2001) by BaBar and Belle

sin2β history (1998-2005)
\[ \sin^2 \phi_1 = 0.678 \pm 0.025 \text{ (4\% accuracy)} \]

\[ (\phi_1 = 21.3 \pm 1.0 \text{ deg.}) \]

World avg. (i.e. with OPAL, ALEPH, CDF)

Average with B factories only

PRL 98, 031802 (2007)

hep-ex/0703021
Direct CPV in $B^0 \rightarrow J/\psi K^0$

$C = 0.049 \pm 0.022 \pm 0.017$
with all charmonium modes combined

$C(J/\psi K^0)$

- BABAR: $0.035 \pm 0.025 \pm 0.018$
- Belle: $-0.018 \pm 0.021 \pm 0.014$
- Combined: $0.002 \pm 0.021$
### Systematic uncertainties

<table>
<thead>
<tr>
<th>Source/sample</th>
<th>Sin2φ₁</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertexing</td>
<td>0.012</td>
<td>0.009</td>
</tr>
<tr>
<td>Flavor tagging</td>
<td>0.004</td>
<td>0.003</td>
</tr>
<tr>
<td>Δt Resolution</td>
<td>0.006</td>
<td>0.001</td>
</tr>
<tr>
<td>Physics parameters</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Possible fit bias</td>
<td>0.007</td>
<td>0.004</td>
</tr>
<tr>
<td>BG fractions (J/ψKₛ)</td>
<td>0.003</td>
<td>0.001</td>
</tr>
<tr>
<td>BG fractions (J/ψK_L)</td>
<td>0.005</td>
<td>0.002</td>
</tr>
<tr>
<td>BG Δt</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Tag-Side interference</td>
<td>0.001</td>
<td>0.009</td>
</tr>
<tr>
<td>total</td>
<td>0.017</td>
<td>0.014</td>
</tr>
</tbody>
</table>

Uncertainties from vertex reconstruction ~ 0.01
OK for present B factories, key for more precise measurements at Super B
**b → s tCPV: One of the best new physics probes**

**Method:** Compare

\[ S(\phi K^0) \text{ with } S(J/\psi K^0) \]

SM prediction:

\[ \Delta S \equiv S(\phi K^0) - S(J/\psi K^0) \approx 0 \]

New CP-violating phase can enter even if SUSY scale is above 2TeV.
Mar. 2007: $\phi_1$ with $b \rightarrow s$ Penguins

$\sin(2\beta^{\text{eff}}) = \sin(2\phi_1^{\text{eff}})$

More statistics crucial for mode-by-mode studies

Smaller than $b \rightarrow c \bar{c}s$ in all of 9 modes

Theory tends to predict positive shifts (originating from phase in $V_{ts}$)

Naïve average of all $b \rightarrow s$ modes

$\sin2\beta^{\text{eff}} = 0.53 \pm 0.05$

2.6 $\sigma$ deviation between penguin and tree

$(b \rightarrow s)$  $(b \rightarrow c)$
$B^\pm \rightarrow \phi\phi K^\pm$ : ultra-clean mode


- Interference between $B \rightarrow \eta_c(\rightarrow \phi\phi)K$ and 3-body $b \rightarrow s$ process
- $CP$ violation in the SM $\sim 0$, can be $\sim 0.4$ if new physics enters $b \rightarrow s$
- Ultra-clean mode to reconstruct, almost no background

Belle observation (hep-ex/0609016)

CP asymmetry in $\eta_c$ region:

$0.15^{+0.16}_{-0.17} \pm 0.02$
$b \rightarrow c\bar{c}d$

another place to study $\phi_1$

$B^0 \rightarrow D^+D^-$

Evidence for large CPV from Belle

→ Need more data
\[ \phi_2 (\alpha): B^0 \rightarrow \pi^+ \pi^- \]

**Belle 535MBB**

\[ A_{\pi\pi} = +0.55 \pm 0.08 \pm 0.05 \]
\[ S_{\pi\pi} = -0.61 \pm 0.10 \pm 0.04 \]

Direct CPV @ 5.5\( \sigma \)

**BaBar 383MBB**

\[ C_{\pi\pi} (-A_{\pi\pi}) = -0.21 \pm 0.09 \pm 0.02 \]
\[ S_{\pi\pi} = -0.60 \pm 0.11 \pm 0.03 \]

CPV @ 5.5\( \sigma \)
$\phi_2 (\alpha): B^0 \rightarrow \pi \pi$

Constraint on $\phi_2$

$\phi_2 = 92^{+12}_{-10}$
\[ \phi_2 (\alpha): B^0 \to \rho^0 \rho^0 \]

\[ \mathcal{B} = (1.07 \pm 0.33 \pm 0.19) \times 10^{-6} \]

\[ f_L = 0.87 \pm 0.13 \pm 0.04 \]

[BaBar 384MBB]

[hep-ex/0612021] 3.5\sigma
**Constraint on $\phi_2$**

$\phi_2 (\alpha)$: $B^0 \rightarrow \rho \rho$

$B \rightarrow \rho \rho$ is not the best mode anymore

*Before 2006 Summer*

$\phi_2 = 92 \pm 21$ deg.

With New B.F. of $B \rightarrow \rho^0 \rho^0, \rho^- \rho^0$

Triangles were squashed

For further improvement, we need $A_{CP}$ of $B^0 \rightarrow \rho^0 \rho^0$. 

$A^{00}$

$A^{0+}$

$2(\phi_2^{\text{eff}} - \phi_2)$
$\phi_2(\alpha): \mathcal{B}^0 \to (\rho\pi)^0$ Dalitz Analysis

Belle 449MBB

68° < $\phi_2$ < 95°

with other allowed regions

BaBar 375MBB

$\phi_2 = (87 \pm 13)^\circ$

hep-ex/0701015

hep-ex/0703008
DPF/JPS2006: BaBar($\pi\pi/\rho\pi/\rho\rho$) + Belle($\pi\pi/\rho\rho$)

\[ \alpha/\phi_2 = [93^{+11}_{-9}]^\circ \]

consistent with a global fit w/o $\alpha/\phi_2$

\[ \alpha_{\text{Global Fit}} = [98^{+5}_{-19}]^\circ \]

$\mathbf{B \to \rho\pi}$ to be included

- Solution around 0/180deg. is eliminated if $\mathbf{Br(Bs \to K^+K^-)} + \mathbf{SU(3)}$ is used for $\pi\pi$. (see talk by M.Ciuchini)
Direct CP violation and $\phi_3 (\gamma)$

$V_{ud}V_{ub}^*$

$V_{td}V_{tb}^*$

$V_{cd}V_{cb}^*$

$B \rightarrow D(*)K(*)$

Color suppressed

$V_{ub}^*$

$D^0 \rightarrow f_{COM}$

$\lambda^3$

Color allowed

$V_{us}$

$K^+$

$D^0 \rightarrow f_{COM}$

$\lambda^3$

Choice of $f_{COM}$ very important!
$\phi_3$ Summary

$\gamma/\phi_3 = [62^{+38}_{-24}]^\circ$

Improvements with more statistics expected in the near future
Inclusive semileptonic B decays: $B \rightarrow X_cl\nu$

- $V_{cb}$

**METHOD**

3 independent parameters

- $E_l$: lepton energy
- $q^2$: lepton-neutrino mass squared
- $M_x$: hadronic mass

**THEORY**

HQE (Heavy Quark Expansion)

Decay rate with expansion in series of $1/m_b$, non-perturbative parameters extracted from shape information

**EXPERIMENT**

- Rate
- Shape
- $|V_{cb}|$
- $m_b, m_c$
- $\mu^2, \mu^2_\pi$
- $|V_{ub}|$

Inclusive $E_l$ spectrum

Inclusive $M_x$ spectrum

$\mu^2_\pi$
\[ |V_{cb}| = (41.69 \pm 0.33_{\text{fit}} \pm 0.20_{\text{T}}) \times 10^{-3} \]
\[ m_{b}^{1s} = 4.718 \pm 0.030 \text{ GeV} \]
\[ \lambda_1 = -0.30 \pm 0.03 \text{ GeV}^2 \]

1% accuracy**

RESULTS

Inclusive semileptonic B decays: \( B \rightarrow X_c \ell \nu \)

Inputs:
decay rates and moments (shape) from BaBar, Belle, CDF, CLEO, DELPHI

\( B \rightarrow X_s \gamma \)

\( E \gamma \) spectrum also used as an input

** \( B \rightarrow D^{(*)} \ell \nu \) (exclusive)
with LQCD \( \rightarrow \sim 4\% \) accuracy
\[ |V_{ub}| = (4.49 \pm 0.19 \pm 0.27) \times 10^{-3} \sim 7\% \text{ accuracy}^{**} \]

** Method **

Inclusive semileptonic
B decays: \( B \rightarrow X_u l \nu \)

Tagging:
- untagged
- semileptonic tag
- hadronic tag

Theory uncertainties (shape function)
→ several different schemes

\[ |V_{ub}| \sim \frac{\Delta B}{\tau_B R} \]

\( ** \) \( B \rightarrow \pi l \nu \) (exclusive) with LQCD → \( \sim 12\% \) accuracy
Summary of $|V_{cb}|$, $|V_{ub}|$

|          | $|V_{cb}| \times 10^{-3}$ | $|V_{ub}| \times 10^{-3}$ |
|----------|--------------------------|--------------------------|
| Exclusive| 39.4±1.6                 | 3.97±0.55                |
| Inclusive| 41.7±0.4*                | 4.49±0.33                |

*P. Urquijo, CKM2006
other numbers from C. Schwanda, Lathuile2007
Cannot be measured from top semileptonic decays ...

**METHOD1**  Loop diagrams

\[
BF(B \to (\rho/\omega)\gamma) = \frac{V_{td}}{V_{ts}} \left( \frac{m_B^2 - m_\rho^2}{m_B^2 - m_K^2} \right)^3 \zeta^2 (1 + \Delta R)
\]

Inclusive BF(B \to X_s\gamma) for E_\gamma > 1.6\text{GeV} \to |V_{ts}| with \sim 7\% accuracy

Caveat: This assumes the unitarity.

\[
\left| \frac{V_{td}}{V_{ts}}_{\rho\gamma} \right| = 0.197^{+0.019}_{-0.018} \text{(exp)} \pm 0.015 \text{(th)}
\]

Belle

BaBar+Belle(10^{-6})

\[
1.22^{+0.23}_{-0.21} \pm 0.05
\]
\[ \Delta m_q = \frac{G^2_f}{6\pi^2} m_{B_q} M_W^2 f(\frac{m_t^2}{M_W^2}) \eta_{\text{QCD}} B_{B_q} f_{B_q}^2 |V_{tb}^* V_{tq}|^2 \quad q = d, s \]

Box diagrams

\[ \bar{B}_s \to \bar{d} \tau \bar{V}_{td} \to \bar{V}_{ts} V_{td} \]

\[ B_s^0 \to b \bar{V}_{ts} \to \bar{V}_{td} V_{td} \]

BaBar+Belle

\( \sim 1\% \) accuracy

CDF

\( \sim 0.7\% \) accuracy

BaBar

\[ \sqrt{B_{B_d} f_{B_d}} = 244 \pm 26 \text{ MeV} \]

(Okamoto, hep-lat/0510113)

Limits precision on

\[ |V_{td}|, |V_{ts}| \text{ to } \sim 10\% \]

\[ |V_{td}| = (7.4 \pm 0.8) \times 10^{-3} \]

(PDG2006)
\[
\Delta m_d = 0.507 \pm 0.005(1\%) \quad \text{(PDG 2006)}
\]

\[
\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s}}{m_{B_d}} \frac{\xi_1}{\xi_2} \frac{V_{td}}{V_{ts}}^2
\]

\[
\xi = \frac{B(B^0 \rightarrow J/\psi K^0)}{B(B^0 \rightarrow J/\psi K^0)^{\text{th}}} = 1.210 \pm 0.047
\]

\[\pm 0.035 \quad \text{(-4\% accuracy)}\]

\[\Delta m_s = 17.77 \pm 0.10 \text{ (stat.)} \pm 0.07 \text{ (syst.)} \text{ ps}^{-1}
\]

\[V_{td} = 0.2060 \pm 0.0007 \text{ (exp.)} + 0.0081 \text{ (theo.)}
\]
Good overall agreement. O(1) new physics unlikely.
Need to be able to detect O(0.1) effects as the next step.

Kobayashi-Maskawa model of CP violation has been firmly established, just like Newtonian mechanics was established.
Comment on $|V_{ub}|$ tension (1)  

Impact of precise $|V_{ub}|$

✧ Combined average \[ \sin 2\beta = 0.647 \pm 0.024 \] below "tree" value \[ \sin 2\beta = 0.794 \pm 0.045 \]
deduced from $|V_{ub}|$ and $|V_{td}|$
✧ Deviation 2.9\(\sigma\) (!)
✧ Increased precision in $|V_{ub}|$ and recent measurement of $B_s-B_s$ mixing (D0, CDF) crucial
Comment on $|V_{ub}|$ tension (2)

T. Iijima

$|V_{ub}|$ from CKM fit (direct meas. not included) $|V_{ub}|$ from SL

$\text{Br}(B \to \tau\nu) \propto |V_{ub}|^2$

SM formula w/ $f_B = 0.216 \pm 0.022$ GeV

Belle result $\text{Br}=(1.79 +0.72 -0.71 ) \times 10^{-4}$

Improved $\text{Br}(B \to \tau\nu)$ meas. important to disentangle possible origins of the “$V_{ub}$ tension”
Direct CPV in $B^0 \rightarrow K^+\pi^-$ (established in 2004)

\[ A_{K\pi} = -0.107 \pm 0.018 \text{ (stat)} \pm 0.007 \text{ (syst)} \]

(5.5 $\sigma$)

- Direct CPV already observed in K decays. Important to see it in B decays? → Yes! There are well-motivated “B-superweak” models.
  - e.g. Superstring-inspired “B-superweak” model that also allows SUSY EW baryogenesis [M. Brhlik et al., PRL 84, 3041 (2000)].
$A_{CP}(K\pi)$ puzzle?

$$A_{CP}(K^+\pi^0) = +0.047 \pm 0.026$$
$$A_{CP}(K^+\pi^-) = -0.093 \pm 0.015$$

deviation: $0.14/0.03 > 4.6\sigma$

New physics?
**$A_{CP}(K\pi)$ puzzle?**

- Naive expectation, $A_{CP}(K^+\pi^0) \sim A_{CP}(K^+\pi^-)$, is too crude and is not adequate for new physics search. 😞
  - Large color-suppressed tree may exist.
- “Sum rule” offers more precise tests. 😊

D. Atwood, A. Soni, PRD58 (1998) 036005
M. Gronau, PLB627 (2005) 82

\[
A(K^+\pi^-) + A(K^0\pi^+) \frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)} \frac{\tau_0}{\tau_+} = A(K^0\pi^0) \frac{2\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)} \frac{\tau_0}{\tau_+} + A(K^0\pi^0) \frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}
\]

$\mathcal{A}(K^0\pi^0) = -0.16\pm0.04$ (from sum rule)  
$\mathcal{A}(K^0\pi^0) = -0.12\pm0.11$ (tCPV meas.)  

(as of Aug.2006)
Summary of CPV and CKM

• Kobayashi-Maskawa model of CP violation has been established, just like Newtonian mechanics was established.

• Yet there are several inconsistencies that are uncomfortable for the Standard Model.
  – $b \rightarrow s$ CPV (2.6σ)
  – $V_{ub}$ tension (2.9σ if you think $b \rightarrow s$ CPV anomaly is a statistical fluctuation and use combined $\sin 2\phi_1$)

• Only more data will tell us the truth. At the same time, theoretical improvements are also important.
New physics searches
\[ B^\pm \rightarrow \tau^\pm \nu \]

Decays w/ “Missing E(>1\nu)”

**SM:**

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

B decay constant ↔ Lattice QCD

**BSM:** sensitive to New Physics from \( H^\pm \)

Full Reconstruction Method

- Fully reconstruct one of the B's to tag
  - B production
  - B flavor/charge
  - B momentum

Equivalent to "single B meson beam"!

Decays of interests
- $B \rightarrow X u l \nu$
- $B \rightarrow K \nu \nu$
- $B \rightarrow D \tau \nu, \tau \nu$

full (0.1~0.3%) reconstruction
$B \rightarrow D\pi$ etc.

Powerful tools for B decays w/ neutrinos
**B → τν results**

**Belle**


**Belle Hadronic tag**

- $e^+νν$ (3.6%)
- $μ^+νν$ (2.4%)
- $π^+ν$ (4.9%)
- $π^+π^0ν$ (2.0%)
- $πππν$ (0.8%)

$Br(B → τν) = (1.79^{+0.56}_{-0.49} +0.46^{+0.46}_{-0.51}) \times 10^{-4}$

First evidence, 3.5 σ

**BaBar**

hep-ex/0608019

**D 1 ν tag**

$τ^+ → e^+νν$ (eff: 4.1%), $μ^+νν$ (2.4%), $π^+ν$ (4.9%), $π^+π^0ν$ (1.2%)

$(0.88^{+0.68}_{-0.67})(stat.) ± 0.11(syst.) \times 10^{-4}$

No clear signal
Constraints on $H^\pm$ mass

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

Ratio to the SM BF.


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

$r_H = 1.13 \pm 0.51$
Other searches with $B$ decays

- $Br(b \rightarrow s\gamma)$: best NP killer so far
  
<table>
<thead>
<tr>
<th>Experiment</th>
<th>$BR$ (brb)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLEO</td>
<td>3.1 fb$^{-1}$</td>
<td>PRL 87, 251807 (2001)</td>
</tr>
<tr>
<td>BaBar</td>
<td>81.5 fb$^{-1}$</td>
<td>PRD 72, 052004 (2005)</td>
</tr>
<tr>
<td>BaBar</td>
<td>81.5 fb$^{-1}$</td>
<td>hep-ex/0507001</td>
</tr>
<tr>
<td>Belle</td>
<td>5.3 fb$^{-1}$</td>
<td>PLB 511, 151 (2001)</td>
</tr>
<tr>
<td>Belle</td>
<td>140 fb$^{-1}$</td>
<td>PR SL 53, 051803 (2004)</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>hep-ex/0603003</td>
</tr>
</tbody>
</table>

- $B^0 \rightarrow K_s\pi^0\gamma$ tCPV

$A_{FB}(B \rightarrow K^*\ell\ell)$

Extreme NP scenarios are already excluded.
## Tau LFV summary

![Branching Fraction Upper Limits at 90% C.L.](image)

<table>
<thead>
<tr>
<th>Process</th>
<th>$\tau^\pm \rightarrow e^\pm \gamma$</th>
<th>$\tau^\pm \rightarrow \mu^\pm \gamma$</th>
<th>$\tau^\pm \rightarrow e^\pm \pi^0$</th>
<th>$\tau^\pm \rightarrow \mu^\pm \pi^0$</th>
<th>$\tau^\pm \rightarrow e^\pm \eta$</th>
<th>$\tau^\pm \rightarrow \mu^\pm \eta$</th>
<th>$\tau^\pm \rightarrow e^+ \eta'$</th>
<th>$\tau^\pm \rightarrow \mu^+ \eta'$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$1.1 \times 10^{-7}$ (Lumi $\text{fb}^{-1}$)</td>
<td>$0.7 \times 10^{-7}$ (Lumi $\text{fb}^{-1}$)</td>
<td>$1.3 \times 10^{-7}$ (Lumi $\text{fb}^{-1}$)</td>
<td>$1.1 \times 10^{-7}$ (Lumi $\text{fb}^{-1}$)</td>
<td>$1.6 \times 10^{-7}$ (Lumi $\text{fb}^{-1}$)</td>
<td>$1.5 \times 10^{-7}$ (Lumi $\text{fb}^{-1}$)</td>
<td>$2.4 \times 10^{-7}$ (Lumi $\text{fb}^{-1}$)</td>
<td>$1.4 \times 10^{-7}$ (Lumi $\text{fb}^{-1}$)</td>
</tr>
<tr>
<td></td>
<td>$1.2 \times 10^{-7}$ (Lumi $\text{fb}^{-1}$)</td>
<td>$0.5 \times 10^{-7}$ (Lumi $\text{fb}^{-1}$)</td>
<td>$0.8 \times 10^{-7}$ (Lumi $\text{fb}^{-1}$)</td>
<td>$1.2 \times 10^{-7}$ (Lumi $\text{fb}^{-1}$)</td>
<td>$0.9 \times 10^{-7}$ (Lumi $\text{fb}^{-1}$)</td>
<td>$0.7 \times 10^{-7}$ (Lumi $\text{fb}^{-1}$)</td>
<td>$1.6 \times 10^{-7}$ (Lumi $\text{fb}^{-1}$)</td>
<td>$1.3 \times 10^{-7}$ (Lumi $\text{fb}^{-1}$)</td>
</tr>
<tr>
<td></td>
<td><strong>HEP-EX/0609049</strong></td>
<td><strong>HEP-EX/0609049</strong></td>
<td><strong>HEP-EX/0609013</strong></td>
<td><strong>HEP-EX/0609013</strong></td>
<td><strong>HEP-EX/0609013</strong></td>
<td><strong>HEP-EX/0609013</strong></td>
<td><strong>HEP-EX/0609013</strong></td>
<td><strong>HEP-EX/0609013</strong></td>
</tr>
</tbody>
</table>
τ → μγ

- Dominant background: τ → μνν + ISR (90%)
- Small contamination of μμ BG in ΔE>0
(Near) future prospect

Possible sensitivity at 5ab$^{-1}$

- PDG2006
- Belle
- Babar

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

Estimated upper limit range of Br
Evidence for $D^0$ mixing

$D^{*+} \to D^0(K^-\pi^+)\pi^+_\text{tag}$

K. Flood at Moriond EW 2007

- $y'$, $x'^2$ contours computed by change in log likelihood
  - Best-fit point is in non-physical region $x'^2 < 0$, but 1-sigma contour extends into physical region
  - correlation: -0.94
- Contours include systematic errors

Accounting for systematic errors, the no-mixing point is at ~4-sigma contour

$R_D: (3.03 \pm 0.16 \pm 0.06) \times 10^{-3}$
$x'^2: (-0.22 \pm 0.30 \pm 0.20) \times 10^{-3}$
$y': (9.7 \pm 4.4 \pm 2.9) \times 10^{-3}$

* No CPV is seen
Evidence for $D^0$ mixing

$y_{CP} = 1.31 \pm 0.32 \pm 0.25 \%$

$> 3\sigma$ above zero (4.1$\sigma$ stat. only)

(* No CP violation seen)
Search for light dark matter on Upsilon(3S)

Y(3S) runs : 2.9 fb\(^{-1}\) (Feb, 2006 : 4days)

\[ \text{better sensitivity than } \sim 7\text{year } Y(4S) \text{ data} \]

\[ Y(3S) \rightarrow Y(1S)\pi^+\pi^- \]

\[ \text{Br}(Y(1S)\rightarrow \text{invisible}) < 2.5 \times 10^{-3} \ (90\% \text{C.L.}) \]

Prediction is disfavored

\[ N_{\text{signal}} = 38 \pm 39 \]

Y(1S) \rightarrow \text{DM DM}
Future prospects
Efforts for improvements never stop!

→ Oide’s talk

Cosmic-ray $\mu$ in newly-installed BaBar LST sextants (Nov.06)

→ better $\mu$ detection efficiency

Crab cavities installed (Jan.07)

→ luminosity goal = $3 \times 10^{34}$/cm$^2$/s

~2/ab from BaBar+Belle by the end of 2008

BaBar will end in 2008

Belle proposing a major upgrade (= SuperKEKB)
   – part of the “Japanese HEP master plan”
   – luminosity goal : $8 \times 10^{35}$/cm$^2$/s (peak), 50/ab (integrated)
Important topics with 2/ab

- $b \rightarrow s \ t\text{CPV}: 2.6\sigma \rightarrow \sim4\sigma$ (for the same central values)
- Vub tension: $2.9\sigma \rightarrow ?$ (depend on data + theory)
- Improved measurements of $D^0$ mixing
- Improved measurements of $B \rightarrow \tau\nu$
- Evidence for $B \rightarrow \mu\nu$
- More precise angle measurements, in particular $\phi_3$ with significant observation in $B \rightarrow D^{(*)}K^{(*)}$

Other new physics searches may also find something surprising!
### Physics reach at 2/ab

<table>
<thead>
<tr>
<th></th>
<th>Today</th>
<th>2ab$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sin 2\phi_1/\beta(b \to c)$</td>
<td>0.026</td>
<td>0.020</td>
</tr>
<tr>
<td>$\sin 2\phi_1/\beta(b \to s)$</td>
<td>0.05</td>
<td>0.035</td>
</tr>
<tr>
<td>$\phi_2$</td>
<td>11°</td>
<td>6°</td>
</tr>
<tr>
<td>$\phi_3$</td>
<td>19°</td>
<td>12°</td>
</tr>
<tr>
<td>$V_{ub}$ (inclusive)</td>
<td>6.3%</td>
<td>4.9%</td>
</tr>
<tr>
<td>$\Delta m_d$</td>
<td>0.8%</td>
<td>0.8%</td>
</tr>
<tr>
<td>$B(B \to (\rho, \omega)\gamma)$</td>
<td>20.4%</td>
<td>10.3%</td>
</tr>
<tr>
<td>$B(B \to \tau\nu)$</td>
<td>36%</td>
<td>27%</td>
</tr>
<tr>
<td>$A_{FB}(K^{*+}I^+I^-)$</td>
<td>23%</td>
<td>10%</td>
</tr>
</tbody>
</table>

\[ \delta(\bar{\rho},\bar{\eta}) = (10.0\%, 4.4\%) \]

R. Itoh, @LHC upgrade WS, Jan. 2007
World sample: four runs

1985 CLEO \(~0.1\,\text{fb}^{-1}\)
2003 CLEOIII \(0.42\,\text{fb}^{-1}\) → PRL 95, 261801 (2005)
2005 Belle \(1.9\,\text{fb}^{-1}\)
2006 Belle \(21.7\,\text{fb}^{-1}\) (~3 weeks)

- 2 papers on exclusive and inclusive Br
  - PRL 98, 052001 (2007)
  - hep-ex/0610003

\(B_s \rightarrow \gamma\gamma\)

Estimated yields for 100/\text{fb} (6months)

<table>
<thead>
<tr>
<th>Final state</th>
<th>Process</th>
<th>(B_{\text{ext}}) \times 10^{-3}</th>
<th>(\epsilon_{\text{recon}}) (%)</th>
<th>Events/100 fb(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(D_s\pi^+)</td>
<td>spectator</td>
<td>2.9</td>
<td>0.81</td>
<td>220</td>
</tr>
<tr>
<td>(D_s^{*-}\pi^+)</td>
<td>spectator</td>
<td>2.8 \times 10^{-3}</td>
<td>0.45</td>
<td>120</td>
</tr>
<tr>
<td>(D_s^\rho^+)</td>
<td>spectator</td>
<td>7.7 \times 10^{-3}</td>
<td>0.15</td>
<td>110</td>
</tr>
<tr>
<td>(D_s^{*-}\rho^+)</td>
<td>spectator</td>
<td>6.8 \times 10^{-3}</td>
<td>0.081</td>
<td>52</td>
</tr>
<tr>
<td>(D_s^{-}(2317)\pi^+)</td>
<td>spectator</td>
<td>7.3 \times 10^{-4}</td>
<td>0.28</td>
<td>19</td>
</tr>
<tr>
<td>(J/\psi\phi)</td>
<td>color-suppressed spectator</td>
<td>1.3 \times 10^{-3}</td>
<td>1.3</td>
<td>180</td>
</tr>
<tr>
<td>(J/\psi\eta)</td>
<td>color-suppressed spectator</td>
<td>8.5 \times 10^{-4}</td>
<td>0.56</td>
<td>45</td>
</tr>
<tr>
<td>(J/\psi\eta')</td>
<td>color-suppressed spectator</td>
<td>2 \times 10^{-3}</td>
<td>xx</td>
<td>xx</td>
</tr>
<tr>
<td>(D_s^+ D_s^-)</td>
<td>spectator</td>
<td>8.0 \times 10^{-3}</td>
<td>0.020</td>
<td>19</td>
</tr>
<tr>
<td>(D_s^{*-} D_s^-)</td>
<td>spectator</td>
<td>2.0 \times 10^{-2}</td>
<td>0.0099</td>
<td>19</td>
</tr>
<tr>
<td>(D_s^{*-} D_s^+)</td>
<td>spectator</td>
<td>1.9 \times 10^{-2}</td>
<td>0.0052</td>
<td>15</td>
</tr>
<tr>
<td>(\phi\gamma)</td>
<td>b \rightarrow s penguin</td>
<td>4.0 \times 10^{-6}</td>
<td>5.9</td>
<td>22</td>
</tr>
<tr>
<td>(D_s^0 K_s)</td>
<td>color-suppressed spectator</td>
<td>3.0 \times 10^{-4}</td>
<td>1.2</td>
<td>34</td>
</tr>
<tr>
<td>(D_s^- K^+)</td>
<td>spectator, (\phi_s)</td>
<td>2.0 \times 10^{-4}</td>
<td>0.64</td>
<td>12</td>
</tr>
<tr>
<td>(K^- K^+)</td>
<td>b \rightarrow s penguin, b \rightarrow u spectator</td>
<td>4.0 \times 10^{-8}</td>
<td>9.5</td>
<td>36</td>
</tr>
<tr>
<td>(K^+ \pi^-)</td>
<td>b \rightarrow s penguin, b \rightarrow d penguin</td>
<td>5.0 \times 10^{-6}</td>
<td>8.7</td>
<td>4.1</td>
</tr>
<tr>
<td>(\gamma\gamma)</td>
<td>intrinsic penguin</td>
<td>1.0 \times 10^{-6}</td>
<td>20.0</td>
<td>1.9</td>
</tr>
</tbody>
</table>

\(Br < 0.53 \times 10^{-4}\) world best

- Papers based on 22/\text{fb}
data set this year
Why are B factories so successful?

- Great ideas (tCPV, innovative collider design)
- Clear target luminosity from physics requirement
- Competition between two B factories
- Simple physics goal
  - Discover CP violation in the B meson system!
- Large variety of measurements
  - Different star results every year → press release every year
- New ideas for measurements after the experiments started
  - Dalitz analysis for $\phi 3$
  - 3-body CP eigenstates ($KsKsKs$ etc.)
  - Vertexing with $Ks$ and IP constraint ($Ks\pi^0$ etc.)
- Constant improvements
  - continuous injection
  - sophisticated flavor tagging $\epsilon eff = 20\% \rightarrow 30\%$
Integrated Luminosity Projection for SuperKEKB

Projection of KEKB Luminosity

100 \times \text{current statistics}!

Super B factory will produce even more important (fundamental) physics results!

Wonderful physics with this luminosity
Peak Luminosity History and Prospects

L = \(10^{39}/\text{cm}^2/\text{s}\) in 2046 sounds more impressive than 100TeV collider!

Flavor physics will continue beyond your retirement.
Backup Slides
Two asymmetric-energy $B$ factories

PEP-II at SLAC
9GeV (e$^-$) $\times$ 3.1GeV (e$^+$)
peak luminosity:
$1.2 \times 10^{34}$cm$^{-2}$s$^{-1}$

13 countries,
57 institutes,
$\sim$400 collaborators

BaBar

KEKB at KEK
8GeV (e$^-$) $\times$ 3.5GeV (e$^+$)
peak luminosity:
$1.7 \times 10^{34}$cm$^{-2}$s$^{-1}$
world record

11 nations,
80 institutes,
623 persons
I. CP Violation in B Decays
II. Fundamental SM Parameters (Complex Quark Couplings)
III. Beyond the SM (BSM)
IV. Unanticipated New Particles

Unitarity Triangle being overconstrained at B factories

Cabibbo-Kobayashi-Maskawa (CKM) matrix
Some Statistics on B Factories

from spires as of Mar. 27, 2007

<table>
<thead>
<tr>
<th></th>
<th>BaBar</th>
<th>Belle</th>
</tr>
</thead>
<tbody>
<tr>
<td># of “well-known” papers (≥50 citations)</td>
<td>33</td>
<td>41</td>
</tr>
<tr>
<td>Total # of papers</td>
<td>446</td>
<td>297</td>
</tr>
<tr>
<td>Total # of citations</td>
<td>8000</td>
<td>7571</td>
</tr>
</tbody>
</table>

+ many indirect citations through PDG/HFAG citations
\[ V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0 \]

\[ V_{ub} = |V_{ub}| \exp(-i\phi_3) \]

Normalized with \(|V_{cd}V_{cb}^*|\)

\[ \rho = \rho(1 - \lambda^2/2) \]
\[ \eta = \eta(1 - \lambda^2/2) \]

\[ V_{td} = |V_{td}| \exp(-i\phi_1) \]
Time-dependent $CP$ violation (t$CPV$)

“double-slit experiment” with particles and antiparticles

Quantum interference between two diagrams

You need to “wait” (i.e. $\Delta t \neq 0$) to have the box diagram contribution.
tCPV in $B^0$ decays

\[ \Gamma_{B^0}(\Delta t) \]

\[ \Gamma_{\bar{B}^0}(\Delta t) \]

\[ A_{CP}(\Delta t) \equiv \frac{\Gamma_{\bar{B}^0}(\Delta t) - \Gamma_{B^0}(\Delta t)}{\Gamma_{\bar{B}^0}(\Delta t) + \Gamma_{B^0}(\Delta t)} \]

\[ = S \sin \Delta m \Delta t + A \cos \Delta m \Delta t \]

Mixing-induced CPV

Direct CPV

e.g. for $J/\psi K_s$

\[ S = -\xi_{CP} \sin 2\phi_1 = +\sin 2\phi_1 \]

\[ A = 0 \]

to a good approximation

($\xi_{CP}$ : CP eigenvalue)

($A = -C$ a la BaBar)
Principle of tCPV measurement

1. Fully reconstruct one B-meson which decays to CP eigenstate
2. Tag-side determines its flavor (effective efficiency = 30%)
3. Proper time ($\Delta t$) is measured from decay-vertex difference ($\Delta z$)

- $\gamma(4S)$ resonance
- $\beta\gamma = 0.425$ (Belle)
  $0.56$ (BaBar)
- $\Delta t \approx \frac{\Delta z}{\langle \beta\gamma \rangle c}$
- $\Delta z \approx 200 \mu m$ (Belle)
  $\approx 260 \mu m$ (Babar)

Flavor tag and vertex reconstruction
tCPV and $\phi_2(\alpha)$

With the tree diagram only

\[
S\pi^+\pi^- = +\sin 2\phi_2
\]

\[A\pi^+\pi^- = 0\]

Mixing diagram

Decay diagram (tree)

3 measurements: $\pi\pi$, $\rho\rho$, $\rho\pi$
\( \pi \pi : \text{tough bananas} \)

- \( A \pi \pi \) world average \( \rightarrow \) observation of large direct \( CPV \)
- Large penguin diagram (P) \( \sim \) Tree diagram (T)
- Large strong phase difference between P and T

\[
S_{\pi \pi} = \sqrt{1 - A_{\pi \pi}^2 \sin(2\phi_2^{\text{eff}})} \quad \phi_2^{\text{eff}} = \phi_2 + \theta
\]
Isospin analysis: flavor SU(2) symmetry

• Model-independent (symmetry-dependent) method
• SU(2) breaking effect well below present statistical errors

“Penguin pollution” can be removed by isospin analysis
**Interpretation: Direct CP violation+SU(3)**

The results support the expectation from SU(3) symmetry that

\[ A_{CP}(\pi^+ \pi^-) \sim -3 A_{CP}(K^+ \pi^-) \]

N.G. Deshpande and X.-G. He, PRL 75, 1703 (1995)

\[ A_{CP}(K^+ \pi^-) = -0.093 \pm 0.015 \]  
HFAG summer 2006

\[ A_{CP}(\pi^+ \pi^-) \sim +0.3 \]  
ICHEP2006 World Average

\[ A_{CP}(\pi^+ \pi^-) \sim +0.39 \pm 0.07 \]
VV polarization

Polarizations of Charmless Decays

CLEO
Belle
BABAR
CDF
PDG2006
New Avg.

HFAG
AUGUST 2006

\[ \phi K^{*+} \]
\[ \phi K^{*0} \]
\[ K^{*0} \rho^+ \]
\[ K^{*0} \rho^0 \]
\[ \omega \rho^+ \]
\[ K^{*+} \rho^0 \]
\[ \rho^0 \rho^0 \]
\[ \rho^+ \rho^0 \]
\[ \rho^+ \rho^- \]

Longitudinal Polarization Fraction (f_L)
Kobayashi-Maskawa (KM) model of CP violation is now a tested theory. No need to introduce an alternative framework.

Paradigm shift at the beginning of 21st century thanks to two B factories.

New targets

- Effects of TeV new physics $\rightarrow$ deviations from SM
- LFV and new source of CPV
- Hidden flavor symmetry and its breaking