Flavor Physics with Super B Factory

Masashi Hazumi (KEK)
SI2007, Fujiyoshida, Japan, August 4-5, 2007

B meson yield

Super B Factory

B Factory
Outline

I. B Factories – a brief introduction –
II. Super B Factory
III. New physics studies done so far
IV. Hints for new phenomenological studies
I. B Factories
— a brief introduction —
Two asymmetric-energy $B$ factories

PEP-II at SLAC

9GeV ($e^-$) $\times$ 3.1GeV ($e^+$)
peak luminosity:
$1.12 \times 10^{34}$cm$^{-2}$s$^{-1}$

BaBar

13 countries,
57 institutes,
~400 collaborators

KEKB at KEK

8GeV ($e^-$) $\times$ 3.5GeV ($e^+$)
peak luminosity:
$1.71 \times 10^{34}$cm$^{-2}$s$^{-1}$
world record

11 nations,
80 institutes,
623 persons
tCPV in $B^0$ decays

$\Gamma_{B^0}(\Delta t) \quad \Gamma_{B^0}(\Delta t)$

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

$= S \sin \Delta m \Delta t + A \cos \Delta m \Delta t$

(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)

$A_{CP}(\Delta t) = -C \quad \text{a la BaBar}$)
Current $B$ factories: physics of top quarks

$V_{CKM} = \begin{pmatrix}
V_{ud} & V_{us} & V_{ub} \\
V_{cd} & V_{cs} & V_{cb} \\
V_{td} & V_{ts} & V_{tb} 
\end{pmatrix}$

mass and width at energy frontier (FNAL)

coupling (incl. CP-violating phase) at luminosity frontier (KEK, SLAC)
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

The Belle (B Factory) Physics Program
Peak Luminosity History

Peak Luminosity trends in the last 30 years
Integrated luminosity at B factories

~1 Billion $BB$ pairs

Triumph in accelerator science!

KEKB for Belle

KEKB + PEP-II

~710/fb (Jan 07)

~400/fb

PEP-II for BaBar

Integrated Luminosity (log)

KEKB

PEP-II

World
Major achievements at Belle

Belle collaboration
13 countries ~400 collaborators
As of June 2007
# of papers : 219
# of citations: 9883

- Evidence for direct CP violation in $B \rightarrow K^+\pi^-$
- Decisive confirmation of Kobayashi-Maskawa model
- Discovery of $X(3872)$
- Observation of $B \rightarrow \tau\nu$
- Evidence for $b \rightarrow d\gamma$
- Measurements of CP violation in $B \rightarrow \phi K_s, \eta'K_s$ etc.
- Observation of $B \rightarrow K^{(*)}\ell\bar{\ell}$
- Evidence for $D^0$ mixing
- Observation of CP violation in $B \rightarrow \phi K_s, \eta'K_s$ etc.
Comments on CKM measurements

Good overall agreement. O(1) new physics highly 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.
Decay modes for $\phi_1$ and their “cleanness” in SM

\[ \bar{b} \rightarrow \bar{q}q' \quad B^0 \rightarrow f \quad B_s \rightarrow f \quad \text{CKM dependence of } A_f \quad \text{Suppression} \]

| $\bar{b} \rightarrow \bar{c}c\bar{s}$ | $\bar{b} \rightarrow \bar{s}s\bar{s}$ | $\bar{b} \rightarrow \bar{u}u\bar{s}$ | $\bar{b} \rightarrow \bar{c}c\bar{d}$ |
| $\psi K_S$ | $\phi K_S$ | $\pi^0 K_S$ | $D^+ D^-$ |
| $\psi \phi$ | $\phi \phi$ | $K^+ K^-$ | $\psi K_S$ |
| $(V^*_{cb}V_{cs})T + (V^*_{ub}V_{us})P^u$ | $(V^*_{cb}V_{cs})P^c + (V^*_{ub}V_{us})P^u$ | $(V^*_{cb}V_{cs})P^c + (V^*_{ub}V_{us})T$ | $(V^*_{cb}V_{cd})T + (V^*_{tb}V_{td})P^t$ |
| Loop $\times \lambda^2$ | $\lambda^2$ | $\lambda^2$/Loop | Loop |

pure tree

$\bar{b} \rightarrow cud$  $D_{CP} \pi^0$  $D_{CP} K_S$  $(V_{cb}V_{ud})T + (V_{ub}V_{cd})T$  $\lambda^2$

taken from a review “CP violation” in PDG2005 (D.Kirkby, Y.Nir)
Mar. 2007: $\phi_1$ with $b \to s$ Penguins

$\sin^2\phi_1^{\text{eff}}$ in $b \to sqq$ penguin: WA (March 2007)

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

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

Naïve average of all $b \to s$ modes

$\sin^2\beta_{\text{eff}} = 0.53 \pm 0.05$

2.6 $\sigma$ deviation between penguin and tree ($b \to s$) ($b \to c$)

More statistics crucial for mode-by-mode studies
ダメだこりゃ
(Oh no！)

おもしれー
(Interesting！)

2004年の解析の最前線にて撮影（モデル：日下君、樋口君）
Summary of NP searches at B factories

• 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.
  – $b \rightarrow s \text{tCPV} (2.6\sigma)$
  – $V_{ub}$ tension (2.9$\sigma$ if you think $b \rightarrow s \text{tCPV}$ anomaly is a statistical fluctuation and use combined $\sin^2\phi_1$)
  – (several other “puzzles”: polarization, $K\pi$, etc.)

• Only more data will tell us the truth. At the same time, theoretical improvements are also important.
II. Super B Factory
SuperKEKB chronicle

- 2001: Activity started
- 2004
  - SuperKEKB LoI (276 authors)
  - Physics part posted on hep-ex (hep-ex/0406071)
- 2005
  - First budget request from KEK (“gaisan” request) to MEXT
- 2006
  - Target luminosity doubled: $4 \times 10^{35} \rightarrow 8 \times 10^{35}$
  - JAHEP “Prospects for Elementary Particle Physics”
    - KEKB major upgrade as part of JAHEP master plan
- 2007
  - Crab cavities installed, under detailed evaluation
  - Update of SuperKEKB physics part in preparation
  - Starting detector optimization studies
SuperKEKB overview

Peak luminosity: \(8 \times 10^{35}/\text{cm}^2/\text{s}\) (~50 \times\) present world record from KEKB)

Integrated luminosity: 50/ab (~100 \times\) present world record from KEKB)

\[ L = \frac{\gamma}{2\sigma_{\ell}} \left( 1 + \frac{\sigma^*}{\sigma} \right) \left( \frac{I}{\beta_{\perp} \rho} \right) \]

will reach \(8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}\).
SuperB: new approach based on ILC FF and DR

Crossing angle = 2*17 mrad

ILC DR & FF
DR damping time as PEPII-KEKB
1.5 times DR bunch charges
Same ILC-IP betas
Crossing angle and “crab waist” to minimize bb blowup
Design based on recycling all PEP hardware, Bends, Quads and Sexts, and RF system.
Low ΔE and wall power.

<table>
<thead>
<tr>
<th>Nominal</th>
<th>Parameter</th>
</tr>
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<tbody>
<tr>
<td>PARAMETER</td>
<td>LER</td>
</tr>
<tr>
<td>Particle type</td>
<td>e+</td>
</tr>
<tr>
<td>Energy (GeV)</td>
<td>4</td>
</tr>
<tr>
<td>Luminosity x 10^{36}</td>
<td>1</td>
</tr>
<tr>
<td>Beam current (A)</td>
<td>2.28</td>
</tr>
<tr>
<td>Beta y* (mm)</td>
<td>0.30</td>
</tr>
<tr>
<td>Emit y (pmr)</td>
<td>4</td>
</tr>
<tr>
<td>Sigma y* (microns)</td>
<td>0.035</td>
</tr>
</tbody>
</table>

SuperB Contributors (Basic concepts):
BINP: KEKB: LNF: Pisa:SLAC
Peak Luminosity History and Prospects

Major upgrade or KEKB (SuperKEKB)

8x10^{35}
Integrated Luminosity Projection for SuperKEKB

Projection of KEKB Luminosity

Physics case with 50/ab

100 × current statistics
1000 × \int \mathcal{L} dt for first observation of CPV in B → J/\psi K^0

Wonderful physics with this luminosity

~10^{11} B mesons
~10^{11} \tau, charm
Much better view!!

SuperKEKB

We are here.
Discoveries through quantum effects of virtual particles may uncover new physics that cannot be detected at the energy frontier.
Present flavor physics in one page

Elucidation of the pattern of flavor symmetry breaking (highly experiment-driven, seeking a new hypothesis on flavor)

Low-energy Effective Field Theory (EFT)*

\[ \mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \frac{1}{\Lambda} \mathcal{L}_5 + \frac{1}{\Lambda^2} \mathcal{L}_6 + \ldots \]

\[ \mathcal{L}_{\text{SM}} = \mathcal{L}_{\text{gauge}} + \mathcal{L}_{\text{matter}} + \mathcal{L}_{\text{Yukawa}} + \mathcal{L}_{\text{Higgs}} \]

* [e.g. D’Ambrosio-Giudice-Isidori-Strumia 2002]

- U(3)^5 flavor symmetry broken by \( \mathcal{L}_{\text{Yukawa}} \)
  - L, B “accidentally” conserved
  - CP broken
- No “flavor principle”
  - parameters in \( \mathcal{L}_{\text{Yukawa}} \) (mixings, masses) determined experimentally
- Mysterious pattern in CKM/masses
  - Hidden flavor symmetry?

- \( \Lambda/4\pi \lesssim O(1) \text{ TeV} \) to resolve Higgs quadratic divergence
  - Sizable effects in flavor sector allowed (“no effect” is extraordinary)
  - Fruitful synergy with energy frontier
- Violation of L, B, CP (not protected by any principle) expected
  - can be discovered (with luck) “at any time”
Quark Flavor Physics

New Physics (NP)
to save EWSB,
to supply DM,
to save GUT,
SUSY, ED, LHT, ...

$E_{\text{NP}}$ not far from $M_Z$

Beyond CKM

dark flavor ?
Super precise measurements at SuperKEKB

- If “dark flavor” discovered
  - Direct detection of new physics in the flavor sector, i.e. revolution in flavor physics
  - If TeV NP found at LHC, SuperKEKB will measure off-diagonal parameters of NP.

- If “dark flavor” not discovered
  - NP below 1TeV severely constrained even assuming Minimal Flavor Violation (MFV)
    - $M_{NP} > 1.5$TeV for large $\tan\beta$, $M_{NP} > 0.6$TeV only for small $\tan\beta$
    (CERN flavor workshop yellow report in preparation)
  - NP at energy scales inaccessible at energy frontier also constrained
III. New physics

studies done so far
Examples of physics studies at SuperKEKB

1. Are there new CP-violating phases?
2. Are there new right-handed currents?
3. Are there effects from new Higgs fields?
4. Are there new flavor violation?
5. Is there new flavor symmetry to explain the CKM hierarchy?

1) $tCPV$ in $B^0 \rightarrow \phi K^0, \eta' K^0, K_s K_s K_s$
2) $tCPV$ in $B^0 \rightarrow K_s \pi_0 \gamma$
3) $B \rightarrow \tau \nu, \mu \nu, D \tau \nu$
4) $\tau \rightarrow \mu \gamma$
5) Unitarity triangle with $O(1)\%$ precision

$tCPV$: time-dependent $CP$ Violation

Key measurements to answer questions above.
Unique at an e+e- B factory (difficult at a hadron machine)
New CP Violation in $b \rightarrow s$: SuperKEKB projection

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

SM prediction

some of recent QCDF estimates

$\sin 2\beta_{eff}^f - \sin 2\beta$

$\phi K_s$
$\eta K_s$
$\pi K_s$
$c K_s$
$K K K_s$
$3 K_s$

$\Delta \sin 2\beta$

$\Delta S$ Uncertainty

Integrated luminosity (ab$^{-1}$)

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

New Physics
(SUSY GUT, Warped Extra Dimension,
String-inspired MSSM, ...)}
$B \rightarrow \phi K^0$ at 50/ab
with present WA value
**b → s time-dependent CP Violation (tCPV)**

Method: Compare $S(\phi K^0)$ with $S(J/\psi K^0)$

SM prediction:

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

SUSY as an example

O(1) effect allowed even if SUSY scale is above 2TeV.

New CP-violating phase can enter
### MSSM: Squark mass matrix (down-type)

#### SuperCKM basis

\[
\begin{pmatrix}
    m_{\tilde{d}_L}^2 & m_d(A_d - \mu \tan \beta) & (\Delta_{12}^d)_{LL} & (\Delta_{12}^d)_{LR} \\
    m_{\tilde{d}_R}^2 & (\Delta_{12}^d)_{RL} & (\Delta_{12}^d)_{RR} \\
    m_{\tilde{s}_L}^2 & m_s(A_s - \mu \tan \beta) & m_{\tilde{s}_R}^2 \\
    m_{\tilde{b}_L}^2 & m_b(A_b - \mu \tan \beta) & m_{\tilde{b}_R}^2
\end{pmatrix}
\]

Assuming all \(\Delta\)'s small and squarks nearly degenerate, we can use mass insertion approximation (MIA):

\[
(\delta_{ij}^d)_{AB} = \frac{(\Delta_{ij}^d)_{AB}}{\bar{m}^2}
\]

### Super B factory

#### New particles come with New Flavor Mixing.
SUSY example: $S_{\phi K}$

Allowed region determined from B factory measurements

$S_{\phi K}$

Allowed region in general

G.L.Kane et al., PRD70, 035015 (2004) and private communication with J. Park.
Projection for SuperKEKB (50ab^{-1})

Region for 5\sigma discovery

\propto M_{\tilde{q}}^2/m_{\tilde{q}}

\begin{align*}
M_{\tilde{q}} = m_{\tilde{q}} &= 500\text{GeV}/c^2
\end{align*}

\[ |\delta_{LR(RL)_{23}}| \]

5\sigma Discovery Region
Excluded (90%CL) from B^0\rightarrow K^0 CPV

MFV (e.g. mSUGRA) ?
Gauge-mediation ?

Big impact on SUSY breaking scenario

Big impacts on other NP also
$B^\pm \rightarrow \phi\phi K^\pm$ : 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:

$0.15^{+0.16}_{-0.17} \pm 0.02$

error $\rightarrow \pm 0.014$ at SuperKEKB (50/ab)
Day 2
Outline

I. B Factories – a brief introduction –
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IV. Hints for new phenomenological studies

We are here.
Examples of physics studies at SuperKEKB

1. Are there new CP-violating phases?
2. Are there new right-handed currents?
3. Are there effects from new Higgs fields?
4. Are there new flavor violation?
5. Is there new flavor symmetry to explain the CKM hierarchy?

Key measurements to answer questions above.
Unique at an e+e- B factory (difficult at a hadron machine)
Search for new right-handed currents through CP violation

- SM Electroweak: purely left-handed

\[ \bar{B}^0 \rightarrow K_s \pi^0 \]

almost purely left-handed photon
described with an amplitude for a left-handed photon: \( \psi_L \)

- New right-handed current \( \rightarrow \psi_R \)

Interference b/w \( \psi_L \) and \( \psi_R \) \( \rightarrow \) Large CP violation

Atwood-Gronau-Soni 1997
Atwood-Gershon-Hazumi-Soni 2005
SuperKEKB Projection for \( S(\text{B} \rightarrow \text{Ks}\pi^0\gamma) \)

SM expectation
\[ S \sim -2 \left( \frac{m_s}{m_b} \right) \times \sin^2 \phi_1 \]

NP with different chiral structure makes a large difference

Possible deviation from SM
- O(1): Warped extra dim.
- O(1): L-R symmetric model
- O(0.1): SUSY SU(5)

Vertex detector with a larger radius preferred

\[ \delta S = 0.1 \rightarrow 3.3/ab \]
$S(B \rightarrow Ks\pi^0\gamma)$ in SUSY general mixing framework

Other exp. constraints (Bs mixing, Br(b → s\gamma)) taken into account

J. Foster, K. Okumura, L. Roszkowski, for SuperKEKB physics book update
<table>
<thead>
<tr>
<th>Observable</th>
<th>Belle 2006 (≈0.5 ab(^{-1}))</th>
<th>SuperKEKB (5 ab(^{-1}))</th>
<th>SuperKEKB (50 ab(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hadronic (b \to s) transitions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<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^0 K_S^0 K_S^0})</td>
<td>0.33</td>
<td>0.105</td>
<td>0.037</td>
</tr>
<tr>
<td>(\Delta A_{\pi^0 K_S^0})</td>
<td>0.15</td>
<td>0.072</td>
<td>0.042</td>
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<tr>
<td>(A_{\phi K^+})</td>
<td>0.17</td>
<td>0.05</td>
<td>0.014</td>
</tr>
<tr>
<td><strong>Radiative/electroweak (b \to s) transitions</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(S_{K_S^0 \pi^0 \gamma})</td>
<td>0.32</td>
<td>0.10</td>
<td>0.03</td>
</tr>
<tr>
<td>(R_K)</td>
<td></td>
<td>0.07</td>
<td>0.02</td>
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<tr>
<td>(\mathcal{B}(B \to X_s \gamma))</td>
<td></td>
<td>13%</td>
<td></td>
</tr>
<tr>
<td>(A_{CP}(B \to X_s \gamma))</td>
<td>0.058</td>
<td>0.01</td>
<td>0.005</td>
</tr>
<tr>
<td>(C_9) from (\overline{A}_{FB}(B \to K^* \ell^+ \ell^-))</td>
<td>-</td>
<td>11%</td>
<td>4%</td>
</tr>
<tr>
<td>(C_{10}) from (\overline{A}_{FB}(B \to K^* \ell^+ \ell^-))</td>
<td>-</td>
<td>13%</td>
<td>4%</td>
</tr>
<tr>
<td>(\mathcal{B}(B^+ \to K^+ \nu \nu))</td>
<td>(\dagger \dagger &lt; 9 \mathcal{B}_{SM})</td>
<td>33 ab(^{-1}) for 5\sigma discovery</td>
<td></td>
</tr>
<tr>
<td><strong>Radiative/electroweak (b \to d) transitions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(S_{\rho \gamma})</td>
<td>-</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>(\mathcal{B}(B \to X_d \gamma))</td>
<td>-</td>
<td>17%</td>
<td></td>
</tr>
</tbody>
</table>
$B \to h(*)\nu\nu$: Summary

- Summary of experimental limits:
- Limit on light dark matter based on $K^+\nu\nu$ limits:

Theoretical predictions

The curvature is due to the lower bound on $P^*(K)$

SM branching fractions

K.F. Chen at FPCP07
\[ B^\pm \rightarrow \tau^\pm \nu \]

**Decays w/ “Missing E(>1\nu)”**

SM : \( Br = (1.6 \pm 0.4) \times 10^{-4} \)

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

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**

**BaBar**
hep-ex/0705.1820

**Hadronic tag**
- $e^+\nu\nu$ (3.6%)
- $\mu^+\nu\nu$ (2.4%)
- $\pi^+\nu$ (4.9%)
- $\pi^+\pi^0\nu$ (2.0%)
- $\pi\pi\pi\nu$ (0.8%)

**Hadronic tag + semileptonic tag**
- $e^+\nu\nu$
- $\mu^+\nu\nu$
- $\pi^+\nu$
- $\pi^+\pi^0\nu$

$$\text{Br}(B \to \tau\nu) = (1.79^{+0.56}_{-0.49} \pm 0.46) \times 10^{-4}$$

First evidence, 3.5 $\sigma$

$$\mathcal{B} = (1.20^{+0.40+0.29}_{-0.38-0.30} \pm 0.22) \times 10^{-4}$$

2.6$\sigma$ (3.2$\sigma$ stat.)
Use known $f_B$ and $|V_{ub}|$

Ratio to the SM BF.


$$r_H = \left(1 - \frac{m_B^2}{m_H^2} \tan^2 \beta \right)^2 = 1.13 \pm 0.51$$

THDM type II

U. Haisch
**B → τν: Future Prospect**

**Charged Higgs Mass Reach**

(95.5%CL exclusion @ 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%

\[ \mathcal{B}(B \rightarrow τν) = \frac{G_F^2 m_B}{8\pi} m_τ^2 \left(1 - \frac{m_τ^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 τ_B \]

$B \rightarrow \mu \nu$ (eV)

- Precise $B \rightarrow \tau \nu / \mu \nu \rightarrow$ lepton universality test.
  - Higgs effect itself is universal. $R_{H}^{\tau \nu} = R_{H}^{\mu \nu}$
  - Good probe to distinguish NP models.

\[ \begin{align*}
  SM \\
  Br(\tau \nu) &= 1.6 \times 10^{-4} \\
  Br(\mu \nu) &= 7.1 \times 10^{-7} \\
  Br(e \nu) &= 1.7 \times 10^{-11}
\end{align*} \]

- 3σ at 1.6 ab$^{-1}$
- 5σ at 4.3 ab$^{-1}$

→ good discovery channel at an early stage of SuperKEKB

~50 events @ 5 ab$^{-1}$
~500 events @ 50 ab$^{-1}$

![Graph showing significance vs. Luminosity](image)
**B → D(⁎) τ ν**

- **Semileptonic tauonic decays**
  \[ m_b \tan \beta + m_c \cot \beta \]

\[ \text{Br(SM)} \sim 8 \times 10^{-3} \]

- **Ratio (τ/μ)** is modified by the charged Higgs effect.

- **Provide good cross check to B→τ ν**
  - H-b-u vertex by B→τ ν
  - H-b-c vertex by B→Dτν
  - H-b-t vertex by LHC direct search.

H. Itoh, Y. Okada
**B → D(∗)τν: breaking news!**

We finally see them!

<table>
<thead>
<tr>
<th>Br (%)</th>
<th>Belle</th>
<th>BaBar</th>
<th>SM</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^- \rightarrow D^0 \tau^- \nu$</td>
<td>0.63±0.38±0.10±0.06</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>$B^- \rightarrow D^{∗0} \tau^- \nu$</td>
<td>2.35±0.49±0.22±0.18</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>$B^0 \rightarrow D^+ \tau^- \nu$</td>
<td>1.03±0.35±0.14±0.10</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>$B^0 \rightarrow D^{∗+} \tau^- \nu$</td>
<td>2.02±0.4-0.37±0.37</td>
<td>1.4</td>
<td></td>
</tr>
</tbody>
</table>

May 2007 | July 2007
Observation of $B \to D^* \tau \nu$

talk by K.F. Chen at FPCP07,

*arXiv:0706.4429 [hep-ex]* (A. Matyja et. al., Belle collab.)

A combined maximum likelihood fit (w/ a single $Bf$) to 3 $M_{\text{tag}}$ distributions:

- $D(K\pi), \tau^+(e^+\nu)_{\tau}$
  - $N_S = 20^{+6}_{-5}$

- $D(K\pi\pi^0), \tau^+(e^+\nu)_{\tau}$
  - $N_S = 12^{+6}_{-5}$

- $D(K\pi), \tau^+(\pi^+\nu)_{\tau}$
  - $N_S = 30^{+10}_{-9}$

First observation:

(3 combined)

$Bf(B \to D^* \tau \nu) = 2.02^{+0.40}_{-0.37} \pm 0.36\%$

$\Sigma = 6.7\sigma$ (stat. only) $\Rightarrow 5.8\sigma$ (stat. + syst.)

Consistent with existing SM predictions.
More theoretical work needed for beyond SM interpretation.
$B \to D \tau \nu$: $H^\pm$ Sensitivity

$5/\text{ab} \to M_H > M_W \tan \beta / 11$
$50/\text{ab} \to M_H > M_W \tan \beta / 5$
LFV in $\tau$ decays and SUSY GUT

Br~O(10^{-9}) at SuperKEKB

Belle 535/fb
main background:
$\tau \rightarrow \mu \nu \nu + ISR$

Goto-Okada-Shindo-Tanaka 2006
SUSY breaking at SuperKEKB


Representative SUSY scenarios a la SUGRA

SUSY Models

1. mSUGRA
   - \( \lambda \) soft is flavor blind
   - KM mixings
   - Mixing in \( \tilde{q}_L \)

2. SUSY SU(5) w/ \( V_R \)
   - Large mixing in \( V \)
   - KM mixings
   - Mass of \( V_R \)
   - Degenerate small 2-3 mixing in \( \tilde{d}_R \)
   - Non-degenerate large 2-3 mixing in \( \tilde{d}_R \)

3. U(2) flavor symmetry
   - 1,2 gen. (u,d,c,s,e,\( \mu \)) U(2) doblet
   - 3\textsuperscript{rd} gen. (t,b,\( \tau \)) U(2) singlet
   - \( O(\lambda^2) \) 2-3 mixing in \( \tilde{q}_L \)

Similar SUSY mass spectra (hard to distinguish)
2007 update

$\Delta S(B^0 \rightarrow \phi K^0)$ for 3 SUSY breaking scenarios

$\delta \Delta S(\phi K^0) = \pm 0.029 \text{ (50 ab}^{-1}\text{)}$
2007 update

$S(B^0 \rightarrow K_S \pi^0 \gamma)$ for 3 SUSY breaking scenarios

$\delta S(K_S \pi^0 \gamma) = \pm 0.03 (50 \text{ab}^{-1})$
2007 update

SUSY SU(5)⊕ν_R

(non-degenerate)

\[ S(K_Sπ^0γ) \]

\[ ΔS(ϕK^0) \]

\[ tanβ = 30 \]

\[ M(ν_R) = 4×10^{14} \text{GeV}/c^2 \]
2007 update

SUSY SU(5)⊕ν_R
(non-degenerate)

\[ \text{Br}(\tau \rightarrow \mu \gamma) \]

w/o improvements

with indicative improvements in detectors/analyses

\[ \text{SuperKEKB sensitivity} \]

\[ \tan \beta = 30 \]

\[ M(\nu_R) = 4 \times 10^{14} \text{ GeV}/c^2 \]
“DNA identification” of new physics

D. Hitlin
Unitarity Triangle Fit (50/ab)

<table>
<thead>
<tr>
<th></th>
<th>(\sigma(\bar{\rho}))</th>
<th>(\sigma(\bar{\eta}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belle ((\sim 0.5,\text{ab}^{-1}))</td>
<td>20.0%</td>
<td>15.7%</td>
</tr>
<tr>
<td>SuperKEKB (50,\text{ab}^{-1})</td>
<td>3.4%</td>
<td>1.7%</td>
</tr>
</tbody>
</table>
Generic NP constraints from the Unitarity Triangle fit

Mixing amplitude: \[ M = r_d^2 M_{SM} \exp(-i2\theta_d) \]
Flavor symmetry

Many proposals, not conclusive at the moment. (Observed pattern consistent with many models)

But a very natural thing to consider if one wants to obtain some clue to understand intriguing mass/mixing patterns. → with some flavor symmetry, less than 10 independent parameters to describe 10 observables (6 quark masses + 4 CKM parameters)

• Prospects at SuperKEKB have been checked.
  – Example models with discrete symmetries
    • Q6 (K.S.Babu and J.Kubo 2004): 9 parameters
      – sign ambiguity in one of parameters (Q6+ and Q6−)
    • D7 (S-L.Chen and E.Ma 2005): 9 parameters
    • $S_3 \times Z_2$ (L.Lavoura and E.Ma 2005): 8 parameters

• Results: Testable (falsifiable) → see the next page
Precise $\phi_3$ measurements may play an essential role:
Note that $\phi_3$ is free from hadronic uncertainties!
Super B factory and Super-LHCb

Sensitivity Comparison ~2020

Super-LHCb 100 fb\(^{-1}\) vs Super-B factory 50 ab\(^{-1}\)

SuperB numbers from M Hazumi - Flavour in LHC era workshop; LHCb numbers from Muheim

LHCb
Super B

No IP Neutrals, \(\nu\)

\(B_s\)

Common

• This plot is made by our LHCb friend.
LHCb: 10/fb
Super-LHCb: 100/fb

Quite complementary to each other!
Other studies

- Charm (D mixing etc.)
- Bs physics on Upsilon(5S)
- Upsilon physics (incl. dark matter search)
- Electroweak physics
- Charmed hadrons

Very rich phenomenology

SuperKEKB is a Super Multi-Flavor Factory!
2007 is the year of $D^0$ mixing!

semileptonic, $K^+\pi^-$, $K_s\pi\pi$, $y_{CP}$, $K^+\pi^-\pi^0$, $K^+\pi^-\pi^+\pi^-$, $\psi(3770)$

$y = \Delta \Gamma / (2 \Gamma)$

Large mixing established this year!

Belle + BaBar combined

$-2 \ln \mathcal{L}$

no-mixing point $(0,0)$ has $-2 \Delta \ln \mathcal{L} = 37$, excluded at $5.7 \sigma$

$\Delta m / \Gamma$

SM can accommodate large $y$ ($\sim 0.01$).
CP asym. (currently consistent with 0) is a good probe for NP.
**D^0-\bar{D}^0** Mixing: future prospect

### Mixing

- **Improvements for 50/ab**: modest due to sys. errors

### CP violation

- **A_M**: CPV in mixing
- **\phi**: CPV in interference b/w mixing and decays

**Bright future: please consider how to use them!**
Bs physics in progress in Belle

- Belle ran also on $Y(5S)$
  - June 2005: 1.86 fb$^{-1}$
  - June 2006: 21.7 fb$^{-1}$
- Very smooth running with same level of luminosity as $Y(4S)$ run
- $N(Bs) \sim 2.6 \times 10^6$
First observation of $B_s$ radiative decay

$\mathcal{B}(B_s \rightarrow \phi \gamma) = (5.7^{+1.8}_{-1.5}^{+1.2}) \times 10^{-5}$

$\Rightarrow 18 \pm 6$ signal events

Significance (including systematics) = $\sqrt{2|\ln \mathcal{L} - \ln \mathcal{L}_0|} = 5.5$

New input for $b \rightarrow s \gamma$ penguin

e.g. Direct CPV can be measured. Q to theorists: How useful is it?
Physics on Υ(5S) at super B factory

- $B_s \rightarrow \gamma \gamma$  \textit{SM}: $B_f (B_s \rightarrow \gamma \gamma) = (0.5-1.0) \times 10^{-6}$.  
  SM signal should be measured with few ab$^{-1}$.

- $\Delta \Gamma_s / \Gamma_s$ and phase $\phi_s$  \textit{CP modes}: $J/\Psi \eta$, $\phi \gamma$, $D_s^+ D_s^-$, $K^+ K^-$  
  CP modes can be better reconstructed at superB Factory  
  Precise measurements, lifetime; competitive with LHC

- $B_s \rightarrow D_s^+ K^-$  \textit{Measurement of $\phi_3(\gamma)$ and CPV}  
  Good channel for studies at superB; accuracy?

- $A_{sl} (B_s)$  \textit{SM}: $A_{sl} (B_s) = (2.7 \pm 0.6) \times 10^{-5}$.  
  SM signal can’t be measured; good place for BSM searches

- $B_s \rightarrow \mu^+ \mu^-$  \textit{SM}: $B_f (B_s \rightarrow \mu^+ \mu^-) = (3.4 \pm 0.3) \times 10^{-9}$.  
  Better suited for studies at LHC

- Many decays with $\gamma$, $\pi^0$, $\eta$; inclusive channels (semilept.)
Search for light dark matter on Upsilon(3S)

**Y(3S) runs : 2.9 fb⁻¹**
(Feb, 2006 : 4days)

Better sensitivity than ~7 year Y(4S) data

**Y(3S) → Y(1S)π⁺π⁻**

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

Prediction is disfavored

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

Y(1S) → DM DM

B. McElrath, PRD 72, 103508 (2005)

PRL 98, 132001 (2007)
IV. Hints for new phenomenological studies
For an observable “i”

\[ \Delta_i \pm \tau_i \pm \varepsilon_i \]

Possible deviation from the SM

Theoretical uncertainty

Experimental uncertainty

Requirement for discovery

\[ \sum \equiv \frac{\Delta_i}{\sqrt{\tau_i^2 + \varepsilon_i^2}} > 5 \]
Possible ways to go

For phenomenological studies

• Invent a new observable that satisfies $\Sigma > 5$
• Reduce theoretical uncertainties $\tau_i$ for known observables

For model builders

• Invent a new model that satisfies $\Sigma > 5$
• Invent a new model that never gives sizable effects (けち)

For students

• Join SuperKEKB! Analyses will be extremely interesting and complex, where having theory background is advantageous.
Invent a new observable that satisfies $\Sigma > 5$

- **Utilizing some symmetry**
  - $B \to \phi K$ with isospin symmetry (Gronau-Rosner 2007)

- **Double suppression**
  - $S(B_s \to D K_s)$: uncertainty becomes $\sim O(\lambda^4)$ (Fleischer 2003)
  - $B \to \phi K\gamma$ CPV (uncertainty $\sim O(\lambda^2) \times m_s/m_b$ (Atwood-Gersho-MH-Soni 2007)

- **SuperKEKB at other beam energies**
  - NMSSM in Upsilon decays (Dermisek-Gunion-McElrath 2006)

- ... 

- **Please add more to the list above**
  - Taking a ratio is always a good thing to consider
  - Taking a double-ratio can even be better.
Reduce theoretical uncertainties $\tau_i$ for known observables

- **Data-driven methods**
  - Use more exp. inputs and less QCD calculation
    - See an example in the next slide

- **QCD engineering**
  - pQCD, QCDF, SCET: many studies
  - LQCD for Vub etc.
    - When will LQCD be able to contribute to $B \to \phi K_s$ ?
    - Is some “hybrid” method possible ?
      - e.g. LQCD + QCDF ?
Contributions from doubly-Cabibbo-suppressed SM amplitudes can fake a NP signal

"Data-driven" method to put bounds on th. uncertainties:

- color-allowed emission diagram \( E_1 \) computed in factorization
- leading P term fitted using \( BR_{\text{ave}} \) and direct CP asymmetries
- other hadronic amplitudes varied between 0 and \( E_1 \)

\[ \Delta S(K^0\pi^0) < \sim 0.1 \]

\[ \Delta S(\phi K^0) < \sim 0.2 \]
Invent a new model that satisfies $\Sigma > 5$

- Fairly good amount of SUSY studies. Hope that it is kept active. e.g. more SUSY GUT studies are quite welcome.
  - Also please try to use SuperB information for “cosmic connections” (e.g. Baryogenesis)
- But less studies for other models.
  - Wish: some organized efforts for other models
    - extra dim.
    - Little Higgs and related
      - Caveat: First LHC results expected in 2-3 years
      - Two strategies that are opposite to each other
        » Wait for LHC results to make your targets clearer
        » Hurry now to claim later that you did it first
“Coda”
Asymmetric \( e^+e^- \) \( B \) factories are new powerful tools that human beings began to use at the dawn of the 21st century.

SuperKEKB is a natural extension of KEKB, the world leader of the luminosity frontier.

\[ 8 \times 10^{35}/ \text{cm}^2/\text{s} \] with technologies proven at KEKB, together with a few modifications.

**Physics case with 50/ab**

- \( 100 \times \) current statistics
- \( 1000 \times \int \mathcal{L} dt \) for first observation of CPV in \( B \rightarrow J/\psi K^0 \)

Wonderful physics outputs
KM established as “Classical Flavor Theory”

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

Rich phenomenology in \( b, \tau, c \)
“Super Multi-Flavor Factory”
Prospects for Elementary Particle Physics

The Japan Association of High Energy Physicists (JAHEP)

October 25, 2006

(An excerpt)

We, the Japanese HEP community, recognize that physics at the energy frontier is of primary importance. With this understanding, we give the highest priority to the realization of the ILC. Before the ILC experiment commences, we will also promote flavor physics that is complementary to physics at the energy frontier. We should pursue the above two goals as a single master plan. I would call it “Yukawa mission”.

Based on these achievements, we will endeavor to make neutrino and kaon experiments at J-PARC successful, and promote an upgrade of the B factory to achieve a significant breakthrough in luminosity in order to explore new physics that emerges in the phenomena of b, c and τ decays.
Impact on New Physics

• Grand questions in flavor physics
  – Why three generations?
  – Why masses and mixing parameters with strange patterns?
  – Why did antimatter disappear in the early universe?
  – ...

• The Standard Model (SM) does not give answers
  – Profound principles (of Gauge, Relativity, Quantum)
  – However, “Flavor Principle” is missing

• These exciting questions will remain unanswered even if SUSY is found at LHC.

Long-term step-by-step experimental approach in flavor physics needed to address these grand questions.
Backup Slides I
Advantages of SuperKEKB

- Clean environment → measurements that no other experiment can perform.
  Examples: CPV in $B \to \phi K^0$, $B \to \eta' K^0$ for new phases, $B \to Ks \pi^0 \gamma$ for right-handed currents.

- “$B$-meson beam” technique → access to new decay modes.
  Example: discover $B \to K \nu \bar{\nu}$.

- Measure new types of asymmetries.
  Example: forward-backward asymmetry in $b \to s \mu \mu$, see

- Rich, broad physics program including $B$, $\tau$ and charm physics.
  Examples: searches for $\tau \to \mu \gamma$ and $D-D$ mixing with unprecedented sensitivity.

- No other experiment can compete for New Physics reach in the quark sector.
\[ P(q = \pm 1, \Delta t) = \frac{1}{4\tau} e^{-\frac{\Delta t}{\tau}} \left[ 1 \pm (S \sin \Delta m \Delta t) \right] \otimes R \]

R : detector time resolution
w : wrong tag fraction
(misidentification of flavor)
\( \Leftrightarrow (1-2w) \) quality of flavor tagging

They are well determined by using control sample \( D^* l^\nu, D^{(*)} \pi \) etc…
2006: $B^0 \rightarrow J/\psi K^0$: combined result

$\sin 2\phi_1 = 0.642 \pm 0.031$ (stat) $\pm 0.017$ (syst)

$A = 0.018 \pm 0.021$ (stat) $\pm 0.014$ (syst)

535 M $B\bar{B}$ pairs
Normalized Unitarity Triangle

$$V_{CKM}^*V_{CKM} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

$$|V_{cd}V_{cb}|$$

Normalized with $|V_{cd}V_{cb}|$

$$\bar{\rho} = \rho(1-\lambda^2/2)$$

$$\bar{\eta} = \eta(1-\lambda^2/2)$$

In particular, $V_{td} = |V_{td}|\exp(-i\phi_1)$

$V_{ub} = |V_{ub}|\exp(-i\phi_3)$
**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 ($\Delta z$)

$\beta_\gamma = 0.425$ (Belle)
$0.56$ (BaBar)

$\Delta z \approx \frac{\Delta z}{\langle \beta_\gamma \rangle c}$

$\Delta z \sim 200\mu m$ (Belle)
b → s Penguin Diagrams and New Physics

very sensitive probes for new physics

rare (or subdominant at most) decays, lots of statistics required; just started!

color probe
b → s g

electroweak probe
b → sl+l-, sνν

electromagnetic probe
b → s γ

examples of SM diagrams
MSSM Flavor Physics as an example

\[ (m_{\tilde{q}}^2)_{ij} = \begin{pmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{pmatrix} \]

Off-diagonal terms
Flavor Structure
Luminosity frontier

Diagonal terms
Mass Spectrum
Energy frontier (LHC, LC)

Generic parameterization
for \( b \to s \) (23 \( \to \) 13 for \( b \to d \))

\( M_{\tilde{q}} \) : average squark mass

**Left-handed**

\[
(\delta_{LL}^d)_{23} = \frac{(m_{d_{LL}}^2)_{23}}{M_{\tilde{q}}^2} \\
(\delta_{LR}^d)_{23} = \frac{(m_{d_{LR}}^2)_{23}}{M_{\tilde{q}}^2}
\]

**Right-handed**

\[
(\delta_{RR}^d)_{23} = \frac{(m_{d_{RR}}^2)_{23}}{M_{\tilde{q}}^2} \\
(\delta_{RL}^d)_{23} = \frac{(m_{d_{RL}}^2)_{23}}{M_{\tilde{q}}^2}
\]
\[ A_{CP}(K^+\pi^-) = -0.093 \pm 0.015 \]
$A_{CP}(K\pi)$ 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?
\( A_{\text{CP}}(K\pi) \) puzzle?

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

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

\[
A(K^0\pi^0) = -0.16 \pm 0.04 \text{ (from sum rule)} \quad \text{(as of Aug.2006)}
\]

\[
A(K^0\pi^0) = -0.12 \pm 0.11 \text{ (tCPV meas.)}
\]
Expected Errors on $f_L$

- Scaling from Belle or BaBar results.
- $K^{*0}K^{*0}$ is estimated with $B_f \sim 0.5 \times 10^{-6}$ and an efficiency of 3.6%.
- An 1% systematic uncertainty limitation is assumed (dominated by the uncertainty on detector acceptance).
SuperKEKB Projection for $B \rightarrow Ks\pi^0\gamma$
and other $b \rightarrow s\gamma$ modes

- $A_{CP}(B \rightarrow X_s\gamma)$
  - SM expectation: $A_{CP} = (0.42^{+0.17}_{-0.12})\%$
  - Today: $A_{cp}(B \rightarrow X_s\gamma) = 0.004 \pm 0.037$ (HFAG $\sim 0.35$ ab$^{-1}$)
  - $\delta A_{CP} \sim 1\%$ at 5 ab$^{-1}$, $\delta A_{CP} \sim 0.5\%$ at 50 ab$^{-1}$

- $A_{CP}(B \rightarrow K_s^0\pi^0\gamma)$
  - Today: $S = -0.10 \pm 0.31 \pm 0.7$, $\mathcal{A} = -0.20 \pm 0.20 \pm 0.06$
  - $\delta S = 0.1$ at 5 ab$^{-1}$, $\delta S = 0.03$ at 50 ab$^{-1}$

- $\mathcal{B}(B \rightarrow \rho^0\gamma)$
  - Today: $\mathcal{B}(B \rightarrow \rho\gamma) = (0.91^{+0.19}_{-0.18}) \times 10^{-6}$
  - 10% error at 5 ab$^{-1}$, 5% error at 50 ab$^{-1}$
  - For $V_{td}/V_{ts}$, need significant improvement from Lattice

- $A_{CP}(B \rightarrow \rho^0\gamma)$
  - $\delta S = 0.4$ at 5 ab$^{-1}$, $\delta S = 0.15$ at 50 ab$^{-1}$

Possible deviation
- O(1): Warped extra dim.
- O(1): L-R symmetric model
- O(0.1): SUSY SU(5)
$B \rightarrow X_d \gamma$ at $5 \text{ ab}^{-1}$

- Efficiency 2.9%
- A fit result:
  $\Rightarrow Y = 4249 \pm 224 \pm 888$
- $b \rightarrow s \gamma$ component
  $\pm 20\%$ uncertainty
- Error sources:
  - Stat.: 5%
  - Fit.: 21%
  - Model: 10% (not in Y)
  - Total: 24%

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

- Lower limit on type-II charged Higgs mass for any $\tan \beta$
  (Misiak et al, hep-ph/0609232)

- $M(H^+) > 295$ GeV (95% CL), or $M(H^+) \sim 650$ GeV (?)

- Need to decrease the experimental error!

- Room for other new physics
$A_{FB}(B \to K^* \ell^+ \ell^-)$ from HL6 workshop

- Sensitive to $C_9$ and $C_{10}$ Wilson coefficients
- Full $(q^2, \theta)$ fit with SM $q^2$ dist with leading coefficients only ($A_9$ and $A_{10}$)
- $\delta A_9/A_9 \sim 11\%$
- $\delta A_{10}/A_{10} \sim 13\%$
- at $5 \text{ ab}^{-1}$

(i.e., $\delta A_9/A_9 \sim \delta A_{10}/A_{10} \sim 4\%$ at $50 \text{ ab}^{-1}$)
B $\rightarrow$ K*ll projection at 50/ab

- Systematic error has not been estimated, so we just extrapolate statistical error.
- With 50/ab, we can achieve 4% statistical errors for A_9 and A_{10}, which is comparable to total error for A_7 from $b \rightarrow s\gamma$ ($\sim 2.5(exp) + 2.5(theo) = 3.5\%$?).
- Systematic error will dominate with 50/ab.
- Error for $s_0$ is obtained from this formula $\delta s_0/s_0 = \delta(C_7/C_9)/(C_7/C_9)$, so we can measure $s_0$ with 5% accuracy using 50/ab data sample.
  $$\hat{s}_0 \sim -2\hat{m}_b \text{Re}(C_9/C_7) \sim 0.16$$
**B → K*ll: Comparison with LHCb**

- **K*μμ** (which is Golden mode at LHCb) yield by LHCb is 2.7 times larger than K*ll yield by Super Belle.
  - Need $10^{36}$ machine and better detector (PID, vertex)/analysis.
- **A₇** is fixed to the value obtained from $b \rightarrow sγ$
  - LHCb cannot measure $B(b \rightarrow sγ)$, so they should use our value or float

<table>
<thead>
<tr>
<th>K*μμ l-</th>
<th>evts/year</th>
<th>δA₉</th>
<th>δA₁₀</th>
<th>δA₇ from $b \rightarrow sγ$</th>
<th>δs₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>LoI Belle (e + μ)</td>
<td>N.A.</td>
<td>32%</td>
<td>44%</td>
<td>2.5(exp)+ 2.5(theo) %?</td>
<td>32%</td>
</tr>
<tr>
<td>Toy Belle (e + μ)</td>
<td>1640</td>
<td>11%</td>
<td>13%</td>
<td>2.5(exp)+ 2.5(theo) %?</td>
<td>11%</td>
</tr>
<tr>
<td>Toy Belle (e + μ)</td>
<td>1.7</td>
<td>3 times better</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LHCb (μ only)</td>
<td>4400</td>
<td>6.5%*</td>
<td>6.9%*</td>
<td>N.A.</td>
<td>7.4%</td>
</tr>
<tr>
<td>LHCb (μ only)</td>
<td>&gt;0.5</td>
<td></td>
<td></td>
<td></td>
<td>If A₇ is fixed.</td>
</tr>
</tbody>
</table>

*just scaling Belle value with evts.
Future Prospect: $B \rightarrow K\nu\nu$

- **Belle @ 250fb$^{-1}$ (preliminary)**
  
  Fully reconstructed tag (by modifying the PID criteria used in $B \rightarrow \tau\nu$ analysis).

<table>
<thead>
<tr>
<th>Efficiency(%)</th>
<th>$42.8 \pm 1.8$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal expected</td>
<td>$0.70 \pm 0.03$</td>
</tr>
<tr>
<td>Background expected</td>
<td>$2.6 \pm 1.6$</td>
</tr>
<tr>
<td>Observed Events</td>
<td>$4$</td>
</tr>
</tbody>
</table>

Consistent with BG expected

$$B(B^+ \rightarrow K\nu\bar{\nu}) < 3.6 \times 10^{-5} (90\%\ C.L.)$$

---

<table>
<thead>
<tr>
<th>Signif.</th>
<th>Lum (ab$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$3\sigma$</td>
<td>12</td>
</tr>
<tr>
<td>$5\sigma$</td>
<td>33</td>
</tr>
</tbody>
</table>

Need Super-B!
<table>
<thead>
<tr>
<th>Observable</th>
<th>Belle 2006 (≈0.5 ab⁻¹)</th>
<th>SuperKEKB (5 ab⁻¹)</th>
<th>SuperKEKB (50 ab⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Leptonic/semileptonic B decays</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$B(B^+ \rightarrow \tau^+ \nu)$</td>
<td>3.5σ</td>
<td>10%</td>
<td>3%</td>
</tr>
<tr>
<td>$B(B^+ \rightarrow \mu^+ \nu)$</td>
<td>†† $&lt; 2.4 B_{SM}$</td>
<td>4.3 ab⁻¹ for 5σ discovery</td>
<td></td>
</tr>
<tr>
<td>$B(B^+ \rightarrow D\tau \nu)$</td>
<td>-</td>
<td>7.9%</td>
<td>2.5%</td>
</tr>
<tr>
<td>$B(B^0 \rightarrow D\tau \nu)$</td>
<td>-</td>
<td>28.5%</td>
<td>9.0%</td>
</tr>
<tr>
<td><strong>LFV in τ decays</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$B(\tau \rightarrow \mu \gamma)$</td>
<td>$&lt; 45$</td>
<td>$&lt; 30$</td>
<td>$&lt; 8$</td>
</tr>
<tr>
<td>$B(\tau \rightarrow \mu \eta)$</td>
<td>$&lt; 65$</td>
<td>$&lt; 20$</td>
<td>$&lt; 4$</td>
</tr>
<tr>
<td>$B(\tau \rightarrow \mu \mu \mu)$</td>
<td>$&lt; 209$</td>
<td>$&lt; 10$</td>
<td>$&lt; 1$</td>
</tr>
</tbody>
</table>

**Diagram:**

- **PDG2006**
- **Belle**
- **Babar**

**SuperKEKB**

(5/ab)
Another comment on $|V_{ub}|$ tension

M. Neubert

Moriond EW 2007

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”

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

$|V_{ub}|$ from SL

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

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

Belle result

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

Improved $\text{Br}(B \to \tau \nu)$ meas. important to disentangle possible origins of the “$V_{ub}$ tension”
Prospect of $\sin 2\phi_1$ uncertainty

Assumption:

• Use the same analysis methods as of now.

• Use $B \rightarrow J/\psi K^0$ only.

<table>
<thead>
<tr>
<th>$L/\text{ab}$</th>
<th>Total</th>
<th>Statistical</th>
<th>Systematic</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.492/ab</td>
<td>0.035</td>
<td>0.031</td>
<td>0.017</td>
</tr>
<tr>
<td>5/ab</td>
<td>0.017</td>
<td>0.010</td>
<td>0.014</td>
</tr>
<tr>
<td>50/ab</td>
<td>0.014</td>
<td>0.003</td>
<td>0.013</td>
</tr>
</tbody>
</table>
# Systematic error of $\sin 2\phi_1$

<table>
<thead>
<tr>
<th>Categories</th>
<th>$\sigma(\sin 2\phi_1)$ with 5/ab</th>
<th>$\sigma(\sin 2\phi_1)$ with 535MB$\bar{B}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Vertexing</td>
<td>0.012</td>
<td>0.012</td>
</tr>
<tr>
<td>2. Possible fit bias</td>
<td>0.007</td>
<td>0.002</td>
</tr>
<tr>
<td>3. $\Delta t$ Resolution function</td>
<td>0.006</td>
<td>0.006</td>
</tr>
<tr>
<td>4. BG fractions ($J/\psi K_L$)</td>
<td>0.005</td>
<td>0.002</td>
</tr>
<tr>
<td>5. Wrong tag probability</td>
<td>0.004</td>
<td>0.001</td>
</tr>
<tr>
<td>6. BG fractions ($J/\psi K_S$)</td>
<td>0.003</td>
<td>0.001</td>
</tr>
<tr>
<td>7. Fixed Physics parameters: $\Delta m_d$, $\tau_{B_0}$</td>
<td>0.001</td>
<td>&gt;0.000</td>
</tr>
<tr>
<td>8. BG $\Delta t$</td>
<td>0.001</td>
<td>&gt;0.000</td>
</tr>
<tr>
<td>9. Tag-Side interference</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Total</td>
<td>0.017</td>
<td>±0.013 ±0.003</td>
</tr>
</tbody>
</table>

Independent of the luminosity increase.
## Breakdown of the systematic error from Vertexing

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>$\sigma(\sin 2\phi_1)$ with 535MBB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>IP tube constraint vertex fit</td>
<td>0.0072</td>
</tr>
<tr>
<td>2.</td>
<td>Poor-quality vertex rejection</td>
<td>0.0064</td>
</tr>
<tr>
<td>3.</td>
<td>Imperfect SVD alignment</td>
<td>0.0056</td>
</tr>
<tr>
<td>4.</td>
<td>$\Delta z$ bias</td>
<td>0.0050</td>
</tr>
<tr>
<td>5.</td>
<td>Track error estimation</td>
<td>0.0033</td>
</tr>
<tr>
<td>6.</td>
<td>Track rejection in $B_{tag}$ decay vertexing</td>
<td>0.0026</td>
</tr>
<tr>
<td>7.</td>
<td>$\Delta t$ fit range</td>
<td>0.0002</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>$\pm 0.012$</strong></td>
</tr>
</tbody>
</table>

- **Dominant**
- **Irreducible even with more data**

Possible improvement idea:

As we have more data, we can reject the events with poorer quality to reduce the systematic error.

1. **IP tube constraint fit**
   - Select only the events with the 2 tracks in $CP$ side
2. **Poor-quality vertex cut**
   - Tighten a criteria for the vertex selection.

**Limiting factor is imperfect SVD alignment.**
SuperKEKB projection for $\phi_2$

\[
\rho\pi
\]

\[
\rho\rho
\]

\[
\pi\pi
\]

$1 - C.L.$

$1 - C.L.$

$1 - C.L.$

$1 - C.L.$

$\delta \phi_2 = 1^\circ$

(50/ab)

(w/o $S\rho + \rho -$)

50/ab

5/ab
New idea for $\phi_2$: $B \rightarrow \pi\pi$

$S(B^0 \rightarrow \pi^0\pi^0)$ with external photon conversion

8-fold $\rightarrow$ 2-fold ambiguity

- Easily killed with $\text{Br}(B_S \rightarrow K^+K^-)$
- No non-resonant systematics

50/ab

H. Ishino, M. H, M. Nakao, T. Yoshikawa, hep-ex/0703039
How to kill $\phi_2 \sim 0^\circ/180^\circ$

$\alpha < 2$ implies $P > 30$

$\text{BR}(B_s \rightarrow K^+K^-)$ requires

$P \sim 1$ using SU(3) + reasonable breaking

isospin analysis

isospin analysis + upper bound on $P$

hep-ph/0703073

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**$\phi_3$ and Vub**

Model-indep. approach for $\phi_3$ from B $\to$ DK Dalitz


$\sim 4^\circ$  
$\sim 1^\circ$  
$50/\text{ab}$  
$750/\text{pb}$ (CLEO-c)  
$20/\text{fb}$ (BES-III)

Vub inclusive: 6%

Vub exclusive: $\sim 5\%$ depends on LQCD.
\[ \phi_3 \text{ from } B^\pm \to DK^\pm \text{ Dalitz plot analysis} \]

Use \( B^\pm \to D^{(*)}K^{(*)\pm} \) decays, 3-body final state for \( D \), identical for \( D^0 \) and \( \bar{D}^0 \): \( K_s\pi^+\pi^- \).

Dalitz plot density: \( d\sigma_\pm(m_+^2, m_-^2) \sim |M_\pm|^2 dm_+^2 dm_-^2 \) for neutral \( D \) from \( B^\pm \)

\[
|M_\pm(m_+^2, m_-^2)|^2 = |f_D(m_+^2, m_-^2) + re^{i\delta \pm i\phi_3} f_D(m_-^2, m_+^2)|^2
\]

If \( D^0 \) decay model \( f_D \) is known, parameters \( r, \phi_3 \) and \( \delta \) can be obtained by Dalitz plot analysis of both \( B^+ \) and \( B^- \) data.

\( \bar{D}^0 \to K_S\pi^+\pi^- \) model is extracted from continuum \( (D^{*\pm} \to D\pi^{\pm}) \), parametrized as a set of two-body amplitudes. As a result, model uncertainty \( (\sim 10^\circ \text{ currently}) \).
Model-independent analysis

Densities of $\bar{D}^0$ and $D^0$ Dalitz plots: $p_D = |f_D(m^2_+, m^2_-)|^2$, $\bar{p}_D = |f_D(m^2_-, m^2_+)|^2$.

Density of $D^0 \rightarrow K_S\pi^+\pi^-$ Dalitz plot from $B^\pm \rightarrow DK^\pm$:

$$p_{B^\pm}(m^2_+, m^2_-) = |f_D + r_B e^{\phi_B + \delta_{B}} f_D|^2 = p_D + r_B^2 \bar{p}_D + 2\sqrt{p_D \bar{p}_D}(x_\pm C + y_\pm S)$$

where

$$C(m^2_+, m^2_-) = \cos(\delta_D(m^2_+, m^2_-) - \delta_D(m^2_-, m^2_+)) = \cos \Delta \delta_D \quad x_\pm = \cos(\pm \phi_3 + \delta_D)$$

$$S(m^2_+, m^2_-) = \sin(\delta_D(m^2_+, m^2_-) - \delta_D(m^2_-, m^2_+)) = \sin \Delta \delta_D \quad y_\pm = \sin(\pm \phi_3 + \delta_D)$$

Strong phase difference $\Delta \delta_D$ cannot be obtained from flavor $D$ data, but $\psi(3770) \rightarrow DD$ can be used. Two alternatives:

- Density of $D_{CP} \rightarrow K_S\pi^+\pi^-$ Dalitz plot (from $\psi(3770) \rightarrow D_{CP} D_{K_S\pi^+\pi^-}$):

$$p_{CP\pm}(m^2_+, m^2_-) = |f_D \pm \bar{f}_D|^2 = p_D + \bar{p}_D \pm 2\sqrt{p_D \bar{p}_D}C$$

- Density of two correlated Dalitz plots from $\psi(3770) \rightarrow D_{K_S\pi^+\pi^-} D_{K_S\pi^+\pi^-}$:

$$p_{corr}(m^2_+, m^2_-, m^2_+, m^2_-) = |f_D \bar{f}_D - \bar{f}_D f_D'|^2 = p_D \bar{p}_D + \bar{p}_D p'_D - 2\sqrt{p_D \bar{p}_D p'_D \bar{p}'_D}(CC' + SS')$$
# Impact of CLEO-c

<table>
<thead>
<tr>
<th>Events (CLEO-c)</th>
<th>$K_S\pi^+\pi^-$</th>
<th>$K_L\pi^+\pi^-$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K K$</td>
<td>66</td>
<td>134</td>
</tr>
<tr>
<td>$\pi\pi$</td>
<td>27</td>
<td>62</td>
</tr>
<tr>
<td>$K_S\pi^0$</td>
<td>95</td>
<td>103</td>
</tr>
<tr>
<td>$K_L\pi^0$</td>
<td>93</td>
<td>-</td>
</tr>
<tr>
<td>$K_S\pi^+\pi^-$</td>
<td>180</td>
<td>457</td>
</tr>
</tbody>
</table>

570 CP tags in 281 pb$^{-1}$ → 6-7° sys. err.

~1500 CP tags expected in 750 pb$^{-1}$ → ~4° sys. err.

~1700 "double" Dalitz tags expected in 750 pb$^{-1}$

- Belle Statistics (347 fb$^{-1}$)
  - 1 ab$^{-1}$/B-factory should yield ±6° statistical error
  - 20 ab$^{-1}$/SuperB required for ±2° statistical error

- BESIII: 20 fb$^{-1}$ → 1° systematic

<table>
<thead>
<tr>
<th>Observable</th>
<th>Belle 2006 (≈0.5 ab(^{-1}))</th>
<th>SuperKEKB (5 ab(^{-1}))</th>
<th>SuperKEKB (50 ab(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unitarity triangle parameters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\sin 2\phi_1)</td>
<td>0.026</td>
<td>0.016</td>
<td>0.012</td>
</tr>
<tr>
<td>(\phi_2 (\pi\pi))</td>
<td>11°</td>
<td>10°</td>
<td>3°</td>
</tr>
<tr>
<td>(\phi_2 (\rho\pi))</td>
<td>(68° &lt; \phi_2 &lt; 95°)</td>
<td>3°</td>
<td>1°</td>
</tr>
<tr>
<td>(\phi_2 (\rho\rho))</td>
<td>(62° &lt; \phi_2 &lt; 107°)</td>
<td>3°</td>
<td>1°</td>
</tr>
<tr>
<td>(\phi_2) (combined)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\phi_3 (D^{(<em>)}K^{(</em>)})) (Dalitz)</td>
<td>20°</td>
<td>7°</td>
<td>2.5°</td>
</tr>
<tr>
<td>(\phi_3 (DK^{(*)})) (ADS+GLW)</td>
<td>-</td>
<td>16°</td>
<td>5°</td>
</tr>
<tr>
<td>(\phi_3 (D^{(*)}\pi))</td>
<td>-</td>
<td>18°</td>
<td>6°</td>
</tr>
<tr>
<td>(\phi_3) (combined)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(</td>
<td>V_{ub}</td>
<td>) (inclusive)</td>
<td>7.3%</td>
</tr>
<tr>
<td>(</td>
<td>V_{ub}</td>
<td>) (exclusive)</td>
<td>15%</td>
</tr>
</tbody>
</table>
Two crucial questions:

Can NP be flavour blind?  
No: NP couples to SM which violates flavour

Can we define a “worst case” scenario?  
Yes: the class of model with Minimal Flavour Violation (MFV), namely: no new sources of flavour and CP violation and so: NP contributions governed by SM Yukawa couplings.

\[ \mathcal{H}^{\Delta F=2}_{\text{eff}} = \mathcal{H}_{\text{SM}} + \mathcal{H}_{\text{NP}} = \left( V_{tq} V_{tq'}^* \right)^2 \left( \frac{S_0(x_t)}{\Lambda_0^2} + \frac{a_{\text{NP}}}{\Lambda^2} \right) (\bar{q}' q)_{(V-A)} (\bar{q}' q)_{(V-A)} \]

\[ S_0(x_t) \to S_0(x_t) + \delta S_0, \quad |\delta S_0| = O \left( \frac{4 \Lambda_0^2}{\Lambda^2} \right), \quad \Lambda_0 = \frac{\pi Y_t}{\sqrt{2} G_F M_W} \sim 2.4 \text{ TeV} \]

Today  
\( \Lambda(\text{MFV}) > 2.3 \Lambda_0 \) @95C.L.  
NP masses >200GeV

SuperB  
\( \Lambda(\text{MFV}) > \sim 6 \Lambda_0 \) @95C.L.  
NP masses >600GeV
Evidence for $D^0$ mixing

$D^{*+} \rightarrow D^0\rightarrow K^-\pi^+\pi^+_\text{tag}$

- $y'$, $x'^2$ 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

K. Flood at Moriond EW 2007

384/fb

hep-ex/0703020
Evidence for $D^0$ mixing

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

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

(* No CP violation seen)
Exclusive $B_s \rightarrow \gamma \gamma$ decay

Natural mode to search for BSM effects, many theoretical papers devoted to this decay.

PDG limit: $Bf(B_s \rightarrow \gamma \gamma) < 1.48 \times 10^{-4}$

90% CL UL with 1.86 fb$^{-1}$: $Bf(B_s \rightarrow \gamma \gamma) < 0.53 \times 10^{-4}$.

Expected UL with 100 fb$^{-1}$: $Bf(B_s \rightarrow \gamma \gamma) < 1 \times 10^{-6}$.

SM: $Bf(B_s \rightarrow \gamma \gamma) = (0.5-1.0) \times 10^{-6}$.

BSM can increase $Bf$ up to two orders of magnitude.

a few ab$^{-1}$ for 5$\sigma$ discovery; <1 yr running
Semileptonic Asymmetry

Counting $D_s(*)^+ l^- \nu$ and $D_s(*)^- l^- \nu$ events against a semileptonic or hadronic tag:

- $q\bar{q}$ Background killed by the full reconstruction of the other $B$;
- $BB\pi$ background killed by CKM suppression on reco and tag sides;
- ~15% background from other $B_s$ decays.
- Systematic uncertainties (due to detection asymmetries) taken from the current experiments.

$A_{SL}^s$ accessible only @ $e^+e^-$ machines.

Systematics should quickly become dominant.

TAG-SIDE
Near/far future: search/reconstruct

<table>
<thead>
<tr>
<th>Final state</th>
<th>Process</th>
<th>$B_{est}$</th>
<th>$\epsilon_{recon}(%)$</th>
<th>Events/100 fb$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_s^-\pi^+$</td>
<td>spectator</td>
<td>$2.9 \times 10^{-3}$</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>$D_s^+D_s^-\pi^+$</td>
<td>spectator</td>
<td>$8.0 \times 10^{-3}$</td>
<td>0.020</td>
<td>19</td>
</tr>
<tr>
<td>$D_s^+D_s^-\pi^+$</td>
<td>spectator</td>
<td>$2.0 \times 10^{-2}$</td>
<td>0.0099</td>
<td>19</td>
</tr>
<tr>
<td>$D_s^+D_s^-\pi^+$</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>$4.0 \times 10^{-5}$</td>
<td>5.9</td>
<td>22</td>
</tr>
<tr>
<td>$D^0K_S$</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; $\phi_3$</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>$4.0 \times 10^{-5}$</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>
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 → deviations from SM
- LFV and new source of CPV
- Hidden flavor symmetry and its breaking
With new flavor mixing at SuperB but no new particle at LHC

Measurements at SuperB will imply an upper bound of new physics scale!

~TeV

strong coupling or bound from others

LHC excluded.

\( \phi \) (or \( \phi' \))

Mass

upper bound

New Physics Parameter Space

B Physics

Measurements at SuperB will imply an upper bound of new physics scale!
Major Achievements Expected at SuperKEKB: An Image

Projection of KEKB Luminosity

- New CP-Violating Phase in $b \to s$ with 1 degree precision
- Discovery of $B \to K_{\nu\nu}$
- Precise meas. of $D$ mixing
- Discovery of New Subatomic Particles
- Discovery of new CPV phase in $B \to \phi K$ (for present WA)
- $\sin^2\theta_W$ with $O(10^{-4})$ precision
- Discovery of $B \to \mu\nu$
- Discovery of $B \to D_{\tau\nu}$
- Discovery of CP Violation in Charged $B$ Decays
- Discovery of Direct CP Violation in $B^0 \to K\pi$ Decays (2005)
- Discovery of CP Violation in Neutral $B$ Meson System (2001)
- Observations with $\Upsilon(5S), \Upsilon(3S)$ etc.

“Discovery” with significance $> 5\sigma$
Part of the fascination of flavor is precisely that the chiral and CKM and PMNS structure may thus originate from the GUT or string scale. .... We may have the chance to learn many more clues about flavor physics when we can probe the mechanism of electroweak symmetry breaking at accelerators. Many of the models lead to dozens of new flavor observables, and not just the few additional unmeasured flavor observables that we currently know about.
At any one time there is a natural tendency among physicists to believe that we already know the essential ingredients of a comprehensive theory. But each time a new frontier of observation is broached we inevitably discover new phenomena which force us to modify substantially our previous conceptions. I believe this process to be unending, that the delights and challenges of unexpected discovery will continue always.

Val Fitch, Nobel Prize Speech 1980