Recent Highlights from Belle

Beyond the CP violation measurements

Mikihiko Nakao (KEK)
mikihiko.nakao@kek.jp

8th July 2003, 17h00 — DESY Seminar
The Belle Collaboration  
~300 physicists from 13 regions, 53 institutions

Aomori University  
Budker Institute of Nuclear Physics  
Chiba University  
Chuo University  
University of Cincinnati  
University of Frankfurt  
Gyeongsang National University  
University of Hawaii  
Hiroshima Institute of Technology  
IHEP, Beijing  
ITEP, Moscow  
Kanagawa University  
KEK  
Korea University  
Krakow Institute of Nuclear Physics  
Kyoto University  
Kyungpook National University  
University of Lausanne  
Ljubljana  
University of Melbourne  
Nagoya University  
Nara Women’s University  
National Central University  
National Kaoshing Normal University  
National Lien-Ho College of Technology  
National Taiwan University  
Nihon Dental College  
Niigata University  
Osaka University  
Osaka City University  
Panjab University  
Peking University  
Princeton University  
Saga University  
University of Science and Technology of China  
Seoul National University  
Sungkyunkwan University  
University of Sydney  
Tata University  
Toho University  
Tohoku University  
Tohoku Gakuin University  
University of Tokyo  
Tokyo Institute of Technology  
Tokyo Metropolitan University  
Tokyo University of Agriculture and Technology  
Toyama National College of Maritime Technology  
University of Tsukuba  
Utkal University  
IHEP, Vienna  
Virginia Polytechnic Institute and State University  
Yokkaichi University  
Yonsei University

[= population of those who use $\phi_1, \phi_2, \phi_3$ (instead of $\beta, \alpha, \gamma$, sorry if you confused!)]

(Birthname given by A.I. Sanda)

(Nickname given by somebody else)
Success of the Standard Model ($U(1) \otimes SU(2) \otimes SU(3)$ symmetry) hasn’t been providing answers to our fundamental questions:

- Baryogenesis
- Grand unification of forces
- Quark/lepton families?

Higgs boson is the only missing piece in the SM

What we wish is a theory (and experimental evidence) beyond SM (SUSY?)

(Neutrino mixing is the only available piece of info beyond SM)

CPV in $B$ decays — one more non-trivial test of the SM — has been discovered by two $B$-factories (KEK and SLAC).

The aim is now to find any sign of new physics with more and more data.
**Unitarity of the CKM matrix**

\[ V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0 \]

 UT is already over-constrained at the first round

- **Mixing for** \( \phi_1 (= \beta) \), \( \phi_2 (= \alpha) \) and \( |V_{td}| \)
- **Semileptonic decays for** \( |V_{cb}| \) and \( |V_{ub}| \)
- **Rare decays for** \( \phi_3 (= \gamma) \) and \( |V_{td}| \)

(All the sides and angles are measureable with \( B^0_d \) and \( B^+ \) decays)
Where to look for new physics

- Penguins

\[ b \rightarrow t \rightarrow s,d \]

\[ b \rightarrow t \rightarrow s,d \]

- SM |Amplitude| may be modified
- New phase? \( \Rightarrow \phi_1, \phi_2, \phi_3 \) may differ, or direct CPV

- Mixing

\[ \bar{d} \bar{b} + \bar{d} \bar{b} \]

\[ b \bar{d} + b \bar{d} \]

- Also in trees

\[ B_b \quad D^{(*)} \]

\[ B_b \quad D^{(*)} \]

Recent Highlights from Belle – p.5/60
How the B-factories designed

- Need huge luminosity (the single most important factor)
- Boosted CM frame, vertex detector for $\Delta t$ measurement
- Charged tracks and photons, particle-id for $e$, $\mu$, $\pi$, $K$ and $p$, and $K_L$ detection

$A_{CP} (\Delta t) = \frac{B - \bar{B}}{B + \bar{B}}$

$\Delta t = \Delta z = 0$

$(1 - 2w) \sin 2\phi_1$

Experimetal dilution

No theoretical ambiguity

Recent Highlights from Belle – p.6/60
Outline

- Introduction
- **Next ⇒ KEKB performance surpassing** $\mathcal{L} = 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
- Approaches to go beyond SM
  - Search for new CP Violating $B$ decays
  - Radiative/electroweak rare $B$ decays
- Comments on the new $D_{sJ}$ resonance
KEKB performance --- a brief history

- 1989: KEKB Design started
- 1994: KEKB Construction started
- Jun. 1999: first physics run
- Apr. 2001: surpassed the PEP-II luminosity, $L = 3.4 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$
- Oct. 2002: Accumulated 100 fb$^{-1}$
- 9 May 2003, 07:26: Design luminosity $L = 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ achieved!
- Jul. 2003: Accumulated 158 fb$^{-1}$
KEKB parameters

on 9 May, 2003

<table>
<thead>
<tr>
<th></th>
<th>LER((e^+))</th>
<th>HER((e^-))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>3.5 GeV</td>
<td>8 GeV</td>
</tr>
<tr>
<td>Current</td>
<td>1.41 A</td>
<td>1.06 A</td>
</tr>
<tr>
<td>Number of bunches</td>
<td>1284 (/ 3 km)</td>
<td></td>
</tr>
<tr>
<td>Crossing angle</td>
<td>22 mrad</td>
<td></td>
</tr>
<tr>
<td>Beam lifetime</td>
<td>105 min</td>
<td>247 min</td>
</tr>
<tr>
<td>Peak luminosity</td>
<td>(1.031 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1})</td>
<td></td>
</tr>
</tbody>
</table>

Most of the parameters are close to or better than the design values — simulation did a good job for the accelerator design!
How to get to the design

- **Diligent efforts of KEKB crews!**
  And joint-effort of KEKB-Belle members, too

- **Excellent accelerator design**
  - Infinite crossing angle — simpler IR, less background, heating
  - Large circumference — allows large freedom in the tuning space

- **Flexible control software and quick feedback to the tuning knobs** — good operation points are found in the “adiabatic” on-the-fly tuning during the luminosity runs

![Diagram](image.png)

- $5 \times 10^{10}$ electrons / bunch
- $7 \times 10^{10}$ positrons / bunch
- $1224$ bunches in the ring
- $22$ mrad
- $\sigma(x) = 0.1 \text{mm}$
- $\sigma(y) = 3 \mu\text{m}$
- $\sigma(z) = 7 \text{mm}$
Solving many difficulties

- **LER \((e^+)\) photo-electron instability** — beam size blows up by photo-electron clouds. We added solenoids around the beampipe all along the ring to effectively trap the photo-electrons.

- **Heating and damaging** — many components, such as the moveable beam-masks and bellows, have been damaged and replaced. When the beam (or synchrotron light) spots a single point, serious damages are made. We have been improving / replacing the components.
The best day — 12 May 2003 (0.579 fb⁻¹/day)

Peak Luminosity: 10.461 [nb/sec] @03:48
Integrated Luminosity: 579.10 [pb]

05/12/2003 0:00 - 05/13/2003 0:00 JST

I(HER) = 1.1 A

I(LER) = 1.5 A

\( \mathcal{L} = 10^{34} \text{ cm}^{-2}\text{s}^{-1} \)
158 fb$^{-1}$ collected 
(on resonance: 142 fb$^{-1}$) 
60–90 fb$^{-1}$ used by analyses so far (most of them use 78 fb$^{-1}$) 
First results from 142 fb$^{-1}$ will be ready by LP03
**Belle Detector**

- **SVD** (silicon vtx det.): 3 layer DSSD
- **CDC** (central drift ch.): 50 layers axial+stereo, He + C$_2$H$_5$
- **ACC** (aerogel cherenkov): n=1.015~1.030
- **TOF** (time-of-flight): σ(t) ~ 100 ps
- **ECL** (electromag. cal.): ~9000 CsI(Tl) crystals
- **KLM** (KL and muon det.): 14/15 layers RPC + iron
- **EFC** (extrem fwd cal.): BGO crystals

**1.5T thin SC solenoid**

- **Vtx**: $\sigma_{xy,z} \sim 55\mu m$ @ 1 GeV
- **Trk**: $\sigma_{pt}/p_t = 0.19p_t \oplus 0.34\%$
- **Cal**: $\sigma_E/E \sim 1.8\%$ @ 1 GeV
- **K-id**: $\epsilon \sim 90\%$, fake $\sim 6\%$ up to 3 GeV
- **e-id**: $\epsilon > 90\%$, fake $\sim 0.3\%$ ($> 0.5$ GeV)
- **μ-id**: $\epsilon > 90\%$, fake $< 2\%$ ($> 1$ GeV)

**Belle Detector nicely works at $\mathcal{L} = 10^{34}$ cm$^{-2}$s$^{-1}$!**

No significant performance degradation

Trigger/DAQ works (500 Hz, $\epsilon(B\bar{B}) > 99\%$)

**Probably OK up to a few $\times 10^{34}$ with minor changes**

Recent Highlights from Belle – p.16/60
SuperKEKB

We need significantly more data, as discussed later.

Upgrade scenarios are seriously being studied, aiming for $B$ physics at $10^{35}$ to $10^{36}$ cm$^{-2}$s$^{-1}$ luminosity

Vertexing: Pixel + DSSD
Particle-id: TOP + RICH
Calorimeter: pure CsI for endcap
DAQ/trigger: full replacement

Constraints:
8 GeV x 3.5 GeV
wall plug power < 100MW
crossing angle < 30mrad

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8 GeV x 3.5 GeV
wall plug power < 100MW
crossing angle < 30mrad

One year shutdown to:
install ante chamber
increase RF
modify IR
upgrade Belle

Gradually increase RF

Constraints:
8 GeV x 3.5 GeV
wall plug power < 100MW
crossing angle < 30mrad

Vertexing: Pixel + DSSD
Particle-id: TOP + RICH
Calorimeter: pure CsI for endcap
DAQ/trigger: full replacement
(R&D going on)
Introduction

KEKB performance surpassing $\mathcal{L} = 10^{34}$ cm$^{-2}$s$^{-1}$

Summary — the world record luminosity is the result of the excellent design and enormous diligent efforts. But we do not stop here, aiming for $10^{35}$ and more!

Approaches to go beyond SM

- Next ⇒ Search for new CP Violating $B$ decays
- Radiative/electroweak rare $B$ decays
- Comments on the new $D_{sJ}$ resonance
Now we know that $B \rightarrow J/\psi K^0_S$ and other $b \rightarrow c\bar{c}s$ indirect CPV gives the CP violating phase in $B\bar{B}$ mixing

\[
\frac{d\Gamma(\Delta t)}{d\Delta t} \propto e^{-|\Delta t|/\tau_B} [1 - q\xi_f \sin 2\phi_1 \sin(\Delta m\Delta t)]
\]

Theoretically clean

- SM $b \rightarrow s$ penguin: dominant $t$ and $c$ quark loops give the same phase; $u$ quark loop is suppressed (< 1% effect)
- New physics phase would be overwhelmed by the SM phase
\( b \rightarrow c\bar{c}s \) indirect CPV in one page

- **Summer’02 Belle result**
  - 78 fb\(^{-1}\) data \(\Rightarrow\) 2958 event (81\% purity)
  - Effective flavor tagging efficiency 28.8 \(\pm\) 0.6\%
  - \(\Delta t\) resolution of 1.43 ps \((\tau_B = 1.55\,\text{ps})\)

\[
\sin 2\phi_1(\beta) = 0.719 \pm 0.074 \pm 0.035 \, \text{(Belle)} \\
= 0.741 \pm 0.067 \pm 0.034 \, \text{(BaBar)} \\
= 0.734 \pm 0.055 \, \text{(WA by HFAG)}
\]
Any other indirect CPV?

- Testing ground for the CPV in decay into a CP eigenstate

\[
\frac{d\Gamma(\Delta t)}{d\Delta t} \propto \frac{e^{-|\Delta t|/\tau_B}}{2\tau_B} \left[ 1 - q\xi_f\{S_f \sin(\Delta m \Delta t) + A_f \cos(\Delta m \Delta t)\} \right]
\]

- Examples (rare decays)
  - \( b \to c\bar{c}d \) — \( J/\psi \pi^0, D^*+D^*^- \) …
  - \( b \to s\bar{s}s \) — \( K_S^0 \phi, K_S^0 K^+K^-, K_S^0 \eta' \) …
  - \( b \to s\gamma \) — \( K_1(1270)^0\gamma, K_S^0 \phi\gamma, \ldots \)
  - \( b \to u\bar{u}d \) — \( \pi^+\pi^-, \rho^\pm\pi^\mp \) …

(Angular analysis can disentangle CP of a mixed state for VV and 3-body decays)
Analysis procedure

Reconstructing CP decays

Background suppression

Flavor tagging

$\Delta t$ from vertexing

$\Delta E = E_B^* - E_{\text{beam}}^*$

$M_{bc} = \sqrt{E_{\text{beam}}^*^2 - |p_B^*|^2}$

Very clean for $B \rightarrow J/\psi K_S^0$
Analysis procedure

- Rare decays suffer from huge continuum background ($e^+e^- \rightarrow q\bar{q}$, $q = u, d, s, c$)
  - no abundant $c\bar{c}$ in continuum
- Need a background suppression
- Then $\Delta E$, $M_{bc}$ to reconstruct the signal

**Reconstructing CP decays**

- Background suppression
- Flavor tagging
- $\Delta t$ from vertexing

**Recent Highlights from Belle – p.23**
Analysis procedure

Reconstructing CP decays

Background suppression

Flavor tagging

$\Delta t$ from vertexing

Event shape: moment of the event $\Rightarrow$ Fisher disc.

Fisher disc. and $B$ flight direction $\Rightarrow$ combined into a likelihood ratio

$B \rightarrow \phi K$ signal
Analysis procedure

- Reconstructing CP decays
- Background suppression
- Flavor tagging
- $\Delta t$ from vertexing

Leptons
- High-$p$ $\ell^+$
- Medium-$p$ $\ell^-$

Hadrons
- $K^-$
- $\Lambda^0 \rightarrow p\pi^-$
- High-$p$ $\pi^+$
- Low-$p$ $\pi^-$

$\bar{b} \rightarrow \bar{c}\ell^+\nu$

$B^0$ like signature

Combine all info using a look-up table into a single variable “$r$” ($0 < r < 1$) and assign $q = +1$

($\bar{B}^0$ like signature if opposite charges: $q = -1$)

$b \rightarrow c\ell^+\nu$

$B^0 \rightarrow D^{*-}\pi^+$

$\rho^+$

$\pi^+\pi^0$

$\bar{D}^0\pi^-_{\text{slow}}$

Recent Highlights from Belle – p.25/60
Reconstructing CP decays

Background suppression

Flavor tagging

$\Delta t$ from vertexing

Variable $r$ almost gives the wrong-tag fraction $1 - 2w$, which is measured with a control sample $B^0 \rightarrow D^* - \ell^+ \nu$

$$\frac{N_{OF} - N_{SF}}{N_{OF} + N_{SF}} = \frac{1}{1 - 2w} \cos(\Delta m_d \Delta t)$$

Mixing measurement in 6 $|r|$ bins

Efficiency $> 99.5$

$\varepsilon_{\text{effective}} = 28.8 \pm 0.5$

(exactly the same as $b \rightarrow c\bar{c}s$ CPV measurement)
Maximizing the likelihood to extract info out of $\Delta t$

$$\prod_i L_i = \int (1 - f_{bg}) P_{\text{sig}} R(\Delta t - \Delta t') d\Delta t' + f_{bg} P_{\text{bg}}$$

Use $P_{\text{sig}} = \frac{e^{-|\Delta t|/\tau_B}}{2\tau_B}$ on non-CP events $\Rightarrow$
to get the 12 param. resolution function $R$

(\(z_{CP}, z_{\text{tag}}, \tau_{\text{charm}}, p_B, \text{outlier}\))

For the CP sample, use

$$P_{\text{sig}} = \frac{e^{-|\Delta t|/\tau_B}}{2\tau_B} [1 - \xi_f q(1 - 2w)[S \sin(\Delta m \Delta t) + A \cos(\Delta m \Delta t)]]$$

Reconstructing CP decays

Background suppression

Flavor tagging

$\Delta t$ from vertexing
$b \to s\bar{s}s$ indirect CPV

$\phi K^0_S$

pure $b \to s$ penguin

$K^+ K^- K^0_S$

mixed CP state

$\eta' K^0_S$

with small $u\bar{u}s$ and $d\bar{d}s$

$B^0 \to \phi K^0_S$

$B^0 \to K^+ K^- K^0_S$

$B^0 \to \eta' K^0_S$

Raw asymmetry

$\Delta t$ (ps)

$S = -0.73 \pm 0.64 \pm 0.22$

$A = -0.56 \pm 0.41 \pm 0.16$

$S = +0.49 \pm 0.43 \pm 0.11 \pm 0.00$

$A = -0.40 \pm 0.33 \pm 0.10 \pm 0.00$

$S = +0.71 \pm 0.37 \pm 0.05$

$A = +0.26 \pm 0.22 \pm 0.03$

[PRD67,031102(R) (2003)]

- $B \to \phi K^0_S$ gives negative $S$ ($S \neq \sin 2\phi_1$?)
- Other $S$ are consistent with $\sin 2\phi_1$ ($S \sim \sin 2\phi_1$)
- no sign of non-zero $A$ ($A \sim 0$)
**b → s̅s̅s comparison**

<table>
<thead>
<tr>
<th>Charmonium Modes</th>
<th>BABAR 02</th>
<th>Belle 02</th>
<th>Average (charm)</th>
<th>Average (s penguin)</th>
<th>Average (All)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi K^0_S$</td>
<td>$-0.18 \pm 0.51 \pm 0.07$</td>
<td>$-0.73 \pm 0.64 \pm 0.22$</td>
<td>$0.734 \pm 0.055$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\eta K^0_S$</td>
<td>$0.02 \pm 0.34 \pm 0.03$</td>
<td>$0.71 \pm 0.37 \pm 0.06$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$K K^0_S$</td>
<td>$0.49 \pm 0.43 \pm 0.35$</td>
<td>$0.79 \pm 0.74 \pm 0.035$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Combined with BaBar, we may be seeing some difference between $b \to c\bar{c}s$ and $\bar{s}s$.
Indirect CPV in $b \rightarrow s \gamma$?

- Radiative decays provide a very (theoretically) clean environment to identify new physics in $b \rightarrow s$ penguins.
- Unfortunately, $B^0 \rightarrow K^{*0} \gamma$, $K^{*0} \rightarrow K_S^0 \pi^0$ has no precise vertex.
- Proposed to use $B^0 \rightarrow K_1(1270) \gamma$, $K_1(1270) \rightarrow K_S^0 \rho^0$, $\rho^0 \rightarrow \pi^+ \pi^-$.
  
  [D. Atwood et al., PRL79,185(1997)]

- Our result on $B \rightarrow K\pi\pi\gamma$ shows that it is hard to disentangle $K\rho$ (CP) and $K^*\pi$ (non-CP) states.

  [Belle 29 fb$^{-1}$, PRL89,231801(2002)]

<table>
<thead>
<tr>
<th>$M_{\pi\pi}$ (GeV/c$^2$)</th>
<th>Events/(100 MeV/c$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>40</td>
</tr>
<tr>
<td>0.75</td>
<td>30</td>
</tr>
<tr>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>1.25</td>
<td>10</td>
</tr>
<tr>
<td>1.5</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$M_{K\pi}$ (GeV/c$^2$)</th>
<th>Events/(50 MeV/c$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8</td>
<td>30</td>
</tr>
<tr>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>1.2</td>
<td>10</td>
</tr>
<tr>
<td>1.4</td>
<td>0</td>
</tr>
<tr>
<td>1.6</td>
<td>0</td>
</tr>
</tbody>
</table>
New observation on $B^+ \rightarrow K^+ \phi \gamma$ ($b \rightarrow s\bar{s}s\gamma$) — very clear signal!

$B^0 \rightarrow K^0_S \phi \gamma$ will be useful for indirect CPV

- Not a CP eigenstate, but the CP content can be extracted from an angular analysis (a la $B^0 \rightarrow J/\psi K^{*0}$)
- Need a few $ab^{-1}$ for a meaningful result (but promising)
$B \to \pi^+\pi^-$

- PRL89, 071801 (2002) [45 fb$^{-1}$] has been updated [78 fb$^{-1}$] [hep-ex/0301032, to appear in PRD]
- Improved event selection, error evaluation

![Graph showing $B \to \pi^+\pi^-$ signal, 3-body continuum, and $B \to \pi\pi$ signal, with $\Delta E$ versus $\Delta t$ plots for $q = +1$, $q = -1$, and asymmetry plots for $B \to \pi^+\pi^-$]
**CPV in \( B \rightarrow \pi^+\pi^- \)**

\[
S_{\pi\pi} = -1.23 \pm 0.41 \text{(stat)} \pm 0.07 \text{(syst)} \\
A_{\pi\pi} = +0.77 \pm 0.27 \text{(stat)} \pm 0.08 \text{(syst)} \\
S = A = 0 \text{ is excluded by } 3.4\sigma
\]

(another evidence for CPV in \( B \) decay)

2.2\( \sigma \) hint for direct CPV \((A_{\pi\pi} > 0)\)?

Belle and BaBar disagree by 2.2\( \sigma \):

\[
S_{\pi\pi} = +0.02 \pm 0.34 \pm 0.05, \\
A_{\pi\pi} = -C_{\pi\pi} = +0.30 \pm 0.25 \pm 0.04
\]

**Constraints on \( \phi_2 \)**

With a range of the Penguin/Tree amplitude ratio

\((0.15 < |P|/|T| < 0.45) [\text{SM gives } |P|/|T| = 0.3]\),

and \( \phi_1 = 23.5^\circ \) (strong phase \( \delta \) as free param.),

\[
\Rightarrow 78^\circ < \phi_2 < 152^\circ \text{ (95.5\% C.L.)}
\]
Why not direct CPV in $b \rightarrow s$?

$A_{CP} \sim \times \sin(\phi_{SM} - \phi_{NP}) \times \sin(\delta_{SM} - \delta_{NP})$

- Chances to see the direct CP asymmetry in the charged $B$ decays
- Need also a strong phase difference (need a good luck)
- Pure $b \rightarrow s$ penguin examples: $B^+ \rightarrow \phi K^+$, $B^+ \rightarrow K_S^0 \pi^+$, $B \rightarrow K^* \gamma$

(Direct CPV is expected in the SM in many hadronic rare decays, where Tree and Penguin amplitudes interfere (like in $B \rightarrow \pi^+ \pi^-$), but it is also interesting to see the first partial rate asymmetry in $B$ decays, regardless SM or new physics)
$B^+ \rightarrow K_S^0 \pi^+$ asymmetry

[Belle 29 fb$^{-1}$ PRD66,092002(2002)]

Pure penguin in SM, large $A_{cp}$ was seen?!

<table>
<thead>
<tr>
<th>Year</th>
<th>Data</th>
<th>$A_{cp}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belle 2002</td>
<td>(29 fb$^{-1}$)</td>
<td>$0.46 \pm 0.15 \pm 0.02$ (3$\sigma$)</td>
</tr>
<tr>
<td>Belle 2003</td>
<td>(78 fb$^{-1}$)</td>
<td>$0.07 \pm 0.09 \pm 0.01$ (\pm 0.08 \pm 0.03)</td>
</tr>
</tbody>
</table>

But disappeared now (a good lesson!)
$B \rightarrow K^*\gamma$ asymmetry

- Very small SM $A_{cp}$, less than 1% is predicted
- $A_{cp}$ is zero-consistent in data
- Systematic error is under good control, can go down to 1% with $\times 20$ data

**Belle**
- Preliminary
- 78 fb$^{-1}$

**BaBar**
- 20.7 fb$^{-1}$
- PRL88,101905(2002)

**CLEO**
- 9.1 fb$^{-1}$
- PRL84,5283(2000)

**Average**
- F.Lodovico (FPCP’03)

- $(-0.1 \pm 4.4 \pm 0.8) \times 10^{-2}$
- $(-4.4 \pm 7.6 \pm 1.2) \times 10^{-2}$
- $(8 \pm 13 \pm 3) \times 10^{-2}$
- $(-0.5 \pm 3.7) \times 10^{-2}$
### Direct CPV search (no evidence yet)

<table>
<thead>
<tr>
<th>Particle</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^+\pi^+$</td>
<td>ICHEP'02 [78 fb⁻¹]</td>
</tr>
<tr>
<td>$K^0S\pi^+$</td>
<td>hep-ex/0304035</td>
</tr>
<tr>
<td>$K^+\pi^0$</td>
<td>Moriond'03 [78 fb⁻¹]</td>
</tr>
<tr>
<td>$\eta'K^+$</td>
<td>PLB546,196 (2002) [45 fb⁻¹]</td>
</tr>
<tr>
<td>$\eta^0K^+$</td>
<td>PLB546,196 (2002)</td>
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<tr>
<td>$\phi K^+$</td>
<td>Moriond'03 [78 fb⁻¹]</td>
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<tr>
<td>$\phi K^+$</td>
<td>Moriond'03 [78 fb⁻¹]</td>
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<tr>
<td>$\phi K^+\pi^0$</td>
<td>Moriond'03 [78 fb⁻¹]</td>
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<td>$\pi^+\pi^0$</td>
<td>Moriond'03 [78 fb⁻¹]</td>
</tr>
<tr>
<td>$\omega\pi^+$</td>
<td>PLB546,196 (2002) [78 fb⁻¹]</td>
</tr>
<tr>
<td>$\rho^+\rho^0$</td>
<td>hep-ex/0306007 [78 fb⁻¹]</td>
</tr>
<tr>
<td>$D_s K^-$</td>
<td>hep-ex/0304032</td>
</tr>
<tr>
<td>$D_s K^-$</td>
<td>hep-ex/0304032</td>
</tr>
<tr>
<td>$K^+\gamma$</td>
<td>FPCP'03 [78 fb⁻¹]</td>
</tr>
</tbody>
</table>

### Results

\[ \begin{align*}
-7 \pm 6 \pm 1 \times 10^{-2} \\
7 \pm 9 \pm 1 \times 10^{-2} \\
23 \pm 11 \pm 4 \times 10^{-2} \\
\end{align*} \]
Possibility: $B \rightarrow K\phi\phi$

- 5 $s$-quark final state ($b \rightarrow s\bar{s}s\bar{s}s$)!
- $b \rightarrow s$ penguin $\leftrightarrow b \rightarrow (c\bar{c})s$ interfere, and strong phase from Breit-Wigner from $c\bar{c}$ resonance (16 MeV width for $\eta_c \rightarrow \phi\phi$)
- No SM weak phase difference — if new physics phase, seen as $A_{cp}$! (no need of luck for the strong phases!)

Belle 78 fb$^{-1}$ [hep-ex/0305068]

$\mathcal{B}(B^- \rightarrow \phi\phi K^-; M_{\phi\phi} < 2.85$ GeV) = $(1.8^{+0.8}_{-0.6} \pm 0.2) \times 10^{-6}$

$\mathcal{B}(B^- \rightarrow \eta_c K^-) \times \mathcal{B}(\eta_c \rightarrow \phi\phi) = (2.3^{+1.0}_{-0.7} \pm 0.5) \times 10^{-6}$

First observations, at comparable rates!
More on $B \rightarrow 5$ kaons

$B^+ \rightarrow K^+ K^- K^+ K^- K^+$ decays provide a clean environment: we are updating some of the PDG $J/\psi$ and $\eta_c$ branching fractions by up to an order of magnitude!

<table>
<thead>
<tr>
<th>Decay mode</th>
<th>Branching fractions</th>
<th>Belle [hep-ex/0305068]</th>
<th>PDG2002</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta_c \rightarrow \phi\phi$</td>
<td>$(1.8^{+0.8}_{-0.6} \pm 0.7) \times 10^{-3}$</td>
<td>$(7.1 \pm 2.8) \times 10^{-3}$</td>
<td></td>
</tr>
<tr>
<td>$\eta_c \rightarrow \phi K^+ K^-$</td>
<td>$(2.9^{+0.9}_{-0.8} \pm 1.1) \times 10^{-3}$</td>
<td></td>
<td>N.A.</td>
</tr>
<tr>
<td>$\eta_c \rightarrow 2(K^+ K^-)$</td>
<td>$(1.4^{+0.5}_{-0.4} \pm 0.6) \times 10^{-3}$</td>
<td></td>
<td>$(21 \pm 12) \times 10^{-3}$ (!)</td>
</tr>
<tr>
<td>$J/\psi \rightarrow \phi K^+ K^-$</td>
<td>$(2.4^{+1.0}_{-0.8} \pm 0.3) \times 10^{-3}$</td>
<td></td>
<td>$(0.74 \pm 0.11) \times 10^{-3}$</td>
</tr>
<tr>
<td>$J/\psi \rightarrow 2(K^+ K^-)$</td>
<td>$(1.4^{+0.5}_{-0.4} \pm 0.2) \times 10^{-3}$</td>
<td></td>
<td>$(0.70 \pm 0.30) \times 10^{-3}$</td>
</tr>
</tbody>
</table>
Introduction

KEKB performance surpassing $\mathcal{L} = 10^{34} \text{ cm}^{-2}\text{s}^{-1}$

Approaches to go beyond SM

- **Search for new CP Violating $B$ decays**
  
  *Summary — systematic search for CPV after $\sin 2\phi_1$ has started, but no strong evidence for additional info yet. Many interesting modes with more data: $B \rightarrow \phi K^0_S, K\phi\gamma, \pi^+\pi^-, K^*\gamma, K\phi\phi, \ldots$*

- **Next ⇒ Radiative/electroweak rare $B$ decays**

- Comments on the new $D_{sJ}$ resonance
$b \to s\gamma$

- Penguin diagram can accommodate heavy new particles (SUSY, $H^+$)

Branching fraction in an effective hamiltonian: $\mathcal{H}_{\text{eff}} \propto \sum_{i=1}^{10} C_i(\mu)O_i(\mu)$

\[
\Gamma(b \to s\gamma) = \frac{G_F^2 \alpha_{\text{em}} m_b^5}{32\pi^4} |V_{ts}^* V_{tb}|^2 \left( |C_7^{\text{eff}}|^2 + \frac{1}{m_b}, \frac{1}{m_c} \text{ corrections} \right)
\]

Normalized with $b \to c\ell\nu$: $(G_F^2 m_b^5 |V_{ts}^* V_{tb}|^2$ cancels by assuming $|V_{ts}^* V_{tb}| = |V_{cb}|)$

- Probe for new physics through Wilson coefficient $|C_7|$
  - Branching fraction $\sim 3.5 \times 10^{-4}$ (both in experiments and SM)
  - Calculation completed at NLO

- Tool for $B$-meson dynamics:
  - photon energy spectrum to understand lepton spectra for $V_{ub}$, $V_{cb}$
**b \rightarrow s\gamma** **examples**

### Lower bounds on type-II charged Higgs mass (w/o SUSY)


### BF in particular MSSM scenario

Carena et al., PLB499, 141

\[ m(H^+) = 200 \text{ GeV}, \quad m(\tilde{t}) = 250 \text{ GeV}, \quad \text{others} \ 800 \text{ GeV} \]

### Type-II charged Higgs is very heavy, unless destructive SUSY contributions

<table>
<thead>
<tr>
<th>Type</th>
<th>Quark Masses</th>
</tr>
</thead>
<tbody>
<tr>
<td>type-I</td>
<td>both up and down quarks get their masses from the same Higgs doublet</td>
</tr>
<tr>
<td>type-II</td>
<td>up quark masses from Yukawa couplings to (H_2), while down quarks get masses from couplings to (H_1) (realized in MSSM).</td>
</tr>
</tbody>
</table>
No deviation from SM — many constraints on new physics

\(-0.37 < C_7^{\text{eff}} < -0.17 \) or \(+0.21 < C_7^{\text{eff}} < +0.43 \) (exp.) \(\Leftrightarrow C_7^{\text{eff}} = -0.313 \) (SM)

Need a better precision (experiments and theories) and/or search somewhere else
**$B \to K^*\gamma$**

Precision measurement 10 years after the first $B \to K^*\gamma$ by CLEO

- Large theoretical BF uncertainty to constrain new physics, but,

- Isospin asymmetry will tell the sign of $C_6/C_7$
  
  [Kagan-Neubert PLB539,227(2002)]

SM gives +5 to 10% asymmetry

\[
\Delta_{0+} = \frac{(\tau_{B^+}/\tau_{B^0})\mathcal{B}(B^0 \to K^{*0}\gamma) - \mathcal{B}(B^+ \to K^{*+}\gamma)}{(\tau_{B^+}/\tau_{B^0})\mathcal{B}(B^0 \to K^{*0}\gamma) + \mathcal{B}(B^+ \to K^{*+}\gamma)'}
\]

\[
\Delta_{0+} = +0.003 \pm 0.045\text{(stat)} \pm 0.018\text{(syst)} \implies \text{Need to revisit with more data.}
\]
As it goes through virtual $\gamma/Z$, the decay rate is now a function of the virtuality, or $\hat{s} = s/m_b^2 = (M_{\ell^+\ell^-}/m_b)^2$

\[
\frac{d\Gamma(b \rightarrow s\ell^+\ell^-)}{d\hat{s}} = \left(\frac{\alpha_{em}}{4\pi}\right)^2 \frac{G_F^2 m_b^5 |V_{ts}^* V_{tb}|^2}{48\pi^3} (1 - \hat{s})^2
\]

\[
\times \left[ (1 + 2\hat{s}) \left(|C_9|^2 + |C_{10}|^2\right) + 4 \left(1 + \frac{\hat{s}}{2}\right) |C_7|^2 + 12 \text{Re} (C_7 C_9) \right] + \text{corr.}
\]

- Reliable NNLO calculation only up to $M_{\ell^+\ell^-} \sim 2.4$ GeV ($\hat{s} = 0.25$), calculation breaks down at resonances: $M_{\ell^+\ell^-} \sim M_{J/\psi}$ and above.
- There is large allowed space for $C_9$, $C_{10}$ and the sign of $C_7$.
- Suppressed by $1/\alpha_{em}$, not seen before Belle/BaBar.
Forward Backward Asymmetry

$A_{FB}$ is one of the key observable to distinguish SUSY models.

Examples of $A_{FB}$ with SUSY

![Graph showing $A_{FB}$ as a function of $\hat{s}$]

Either in $B \rightarrow K^* \ell^+ \ell^-$ or in inclusive $B \rightarrow X_S \ell^+ \ell^-$

$[B \rightarrow K\ell^+ \ell^- \text{ cannot be used. } B^0 \rightarrow K_S^0 n(\pi^+ \pi^-) m(\pi^0) \text{ requires flavor tagging}]$
$B \rightarrow K\ell^+\ell^-$ analysis

- Kinematics close to abundant decays:
  $B \rightarrow J/\psi(\rightarrow \ell\ell)K^{(*)}$ or $D(\rightarrow K\pi\pi)$
- Fake $\pi \rightarrow \mu$ is not a problem
- $J/\psi$ and $\psi'$ are vetoed

![Graphs showing dilepton mass distributions]

$J/\psi \rightarrow \mu^+\mu^-$
$J/\psi \rightarrow e^+e^-$
$\psi' \rightarrow l^+l^-$

Recent Highlights from Belle – p.47/60
$B \rightarrow K\ell^+\ell^-$ signal is established

$B \rightarrow K\ell^+\ell^-$ will be there soon

[Belle ICHEP'02 60 fb$^{-1}$]
(update of PRL88,021801(2002))
B → $X_S \ell^+ \ell^-$ analysis

Belle has performed a semi-inclusive analysis for $B \to X_S \ell^+ \ell^-$

Reconstruction

- $X_S = a$ kaon + 0 to 4 pion
  (covers $(82 \pm 2)$% of signal)
- kaon = $K^\pm$ or $K^0_S$
- pion = $\pi^\pm$ or $\pi^0$ (upto 1 $\pi^0$)
- $M_{X_S} < 2.1$ GeV
- lepton = $e$ or $\mu$
- $p(e) > 0.5$ GeV
- $p(\mu) > 1.0$ GeV
- $M_{\ell^+\ell^-} > 0.2$ GeV

Backgrounds

- $B \to J/\psi X_S$
- $B \to X_S \pi^+ \pi^-$
  (These are good control samples, too)
- $b \to c\ell v, c \to s\ell v$
- $b \to c\ell v, \bar{b} \to \bar{c}\ell v$
- $\pi^0 \to e^+ e^- \gamma$
- continuum background
$B \rightarrow X_s \ell^+ \ell^-$ branching fraction

Clear signal (5.4$\sigma$) in $M_{bc} \equiv \sqrt{E^*_{\text{beam}}^2 - |p_B^*|^2}$

Branching fractions in $10^{-6}$

Belle 60 fb$^{-1}$ PRL90,021801(2003)

In agreement with SM (error is still large), constraint on Wilson coefficient $C_9$ and $C_{10}$

Recent Highlights from Belle – p.50/60
**Constraints on $C_9$ and $C_{10}$**

- **$C_7 < 0$ (SM)**
- **$C_7 > 0$ (non-SM)**

- Cutting out some non-SM $C_9$ and $C_{10}$ space from $b \to s\ell^+\ell^-$ with a $|C_7|$ constraint from $b \to s\gamma$

- But sign of $C_7$ is not determined yet

Recent Highlights from Belle – p.51/60
$B \rightarrow X_s \ell^+ \ell^-$ distributions

From bin-by-bin fit to $M_{bc}$

With more data, one can perform $A_{FB}$ measurements

$q^2 = 0$ pole [removed]  
$J/\psi \psi'$ [vetoed]  
$K, K^*$

Belle 60 fb$^{-1}$  
PRL90,021801(2003)

Recent Highlights from Belle – p.52/60
Outline

- Introduction
- KEKB performance surpassing $\mathcal{L} = 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
- Approaches to go beyond SM
  - Search for new CP Violating $B$ decays
  - Radiative/electroweak rare $B$ decays
    
    *Summary — the first inclusive $b \to s\ell^+\ell^-$ has been measured by Belle. So far it does not conflict with SM, but it also demonstrates feasibilities for further studies. $b \to s\gamma$ will provide interesting results, too.*

- Next ⇒ Comments on the new $D_{sJ}$ resonance
New $D_{sJ}$ resonances

BaBar

$D_{sJ}(2317)$

CLEO

$D_{sJ}^*(2459)$

[hep-ex/0304021]  [hep-ex/0305017]
**$D_{sJ}$ at Belle**

$D_{sJ}(2317) \rightarrow D_s^+ \pi^0$ (feed-across accounted)

- $643.2 \pm 50.4$ events
- $\delta M = M(D_{sJ}) - M(D_s^+) = 348.9 \pm 0.5$ MeV
- $M(D_{sJ}) = 2317.4 \pm 0.5$ MeV

$D_{sJ}(2460) \rightarrow D_s^{*+} \pi^0$ (feed-across accounted)

- $79.1 \pm 18.0$ events
- $\delta M = M(D_{sJ}) - M(D_s^{*+}) = 345.4 \pm 1.3$ MeV
- $M(D_{sJ}) = 2457.8 \pm 1.4$ MeV

In agreement with BaBar and CLEO
$D_{sJ}$ properties?

- $D_{sJ}$ are below $D^{(*)}K$ threshold, and have to go through isospin violating channels $D_s^{(*)}\pi^0$
  
  ($D_{sJ}(2460)$ is not $0^+/1^-$ (no $D_{sJ}(2460 \rightarrow DK)$)

- Much lower $D_{sJ}$ masses than expected for missing $J^P = 0^+, 1^+$

<table>
<thead>
<tr>
<th></th>
<th>BaBar</th>
<th>CLEO</th>
<th>Belle</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M(D_{sJ}(2317))$</td>
<td>$(\text{MeV})$ 2316.8 ± 0.4</td>
<td>--</td>
<td>2317.4 ± 0.5</td>
</tr>
<tr>
<td>$M(D_{sJ}(2317)) - M(D_s)$</td>
<td>$(\text{MeV})$</td>
<td>350.0 ± 1.2 ± 1.0</td>
<td>348.9 ± 0.5</td>
</tr>
<tr>
<td>$M(D_{sJ}(2460))$</td>
<td>$(\text{MeV})$</td>
<td>--</td>
<td>2457.8 ± 1.4</td>
</tr>
<tr>
<td>$M(D_{sJ}(2460)) - M(D_s^*)$</td>
<td>$(\text{MeV})$</td>
<td>351.2 ± 1.7 ± 1.0</td>
<td>345.4 ± 1.3</td>
</tr>
</tbody>
</table>

Mass splitting favors the $0^+$ and $1^+$ hypothesis [Bardeen-Eichten-Hill hep-ph/0305049]

CLEO found no signal in other $D_{sJ}$ decays: $D_s^{(*)}\gamma$, $D_s\pi^+\pi^-$, $D_{sJ}(2317) \rightarrow D_s^*\pi^0$ and

$D_{sJ}(2460) \rightarrow D_{sJ}(2317)\gamma$ (no evidence to disfavor $0^+$ and $1^+$)
Radiative $D_{sJ}$ decays

$D_{sJ}(2460) \rightarrow D_s\gamma$ is observed in $B \rightarrow DD_{sJ}(2460)! \ (D = D^0$ or $D^+)$

$J \neq 0$ for $D_{sJ}(2460)$, also $J^P \neq 1^-$ (no decay into $DK$) $\Rightarrow$ uniquely $1^+$

(unless $J \geq 2$, also supported in the angular analysis: $\propto \sin^2 \theta_{\text{hel}}$)

$\mathcal{B}(B \rightarrow DD_{sJ}) \times \mathcal{B}(D_{sJ} \rightarrow D^+_s\gamma) = (5.3^{+1.4}_{-1.3} \pm 1.6) \times 10^{-4}$

$\Leftarrow D_{sJ}(2460) \rightarrow D_s\gamma$ is also observed in continuum

No $D_{sJ}(2317) \rightarrow D_s\gamma$ is found ($J = 0$ is likely $\Rightarrow 0^+$)
$D_{sJ}$ from $B$ decays

$B \to DD_{sJ}(2317), \ D_{sJ}(2317) \to D_s^+\pi^0$

18.8$^{+5.4}_{-4.8}$ events (5.3σ significance)

$\mathcal{B}(B \to DD_{sJ}) \times \mathcal{B}(D_{sJ} \to D_s^+\pi^0)$

$= (9.9^{+2.8}_{-2.5} \pm 3.0) \times 10^{-4}$

$B \to DD_{sJ}(2460), \ D_{sJ}(2460) \to D_s^{*+}\pi^0$

16.7$^{+4.8}_{-4.1}$ events (6.0σ significance)

$\mathcal{B}(B \to DD_{sJ}) \times \mathcal{B}(D_{sJ} \to D_s^+\pi^0)$

$= (25.8^{+7.0}_{-6.0} \pm 7.7) \times 10^{-4}$

$\mathcal{B}(D_{s}\gamma)/\mathcal{B}(D_{s}\pi^0) = 0.21 \pm 0.07 \pm 0.03$

is consistent with prediction for $1^+$


Existence of $B \to DD_{sJ}$ for $j_q = 1/2$, and non-existence for suppressed $j_q = 3/2$ (BaBar) also prefers $j_q = 1/2$ for new $D_{sJ}$

Many supports for ordinary $L = 0, \ j_q = 1/2$ states, despite many theoretical speculations (4-quark state, . . .)
Outline

○ Introduction

○ KEKB performance surpassing $\mathcal{L} = 10^{34}$ cm$^{-2}$s$^{-1}$

○ Approaches to go beyond SM
  ○ Search for new CP Violating $B$ decays
  ○ Radiative/electroweak rare $B$ decays

○ Comments on the new $D_{sJ}$ resonance

Summary — Belle constrains the properties of $D_{sJ}$ using radiative decays and production in $B$ decays. Most likely they are the missing 0$^+$ and 1$^+$ states, although their low mass remains to be a mystery.
Some of the recent Belle highlights are discussed. There are many other topics that I could not cover today: semileptonic $B$ decays ($V_{ub}$, $V_{cb}$), $\phi_3$ measurement, hadronic rare $B$ decays, $\tau$ and charm physics, ...

With more data (158 fb$^{-1}$ this summer, more in the coming years), we will provide exciting results in CPV, radiative/electroweak decays, and many other modes.

Plan is to improve KEKB and Belle, and go beyond $10^{35}$ cm$^{-2}$s$^{-1}$ or more!