A Status Report on Asymmetric B-Factories

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In order to study CPV at $e^+e^-$ colliders ($\psi K_S$):

1. High luminosity. $\sim 10^8 B\bar{B}$ pairs ($\sim 100 \text{ fb}^{-1}$)

2. Good charged particle tracking
   → Cylindrical Drift Chamber

3. Flavor-tagging
   - Lepton identification
     $e$: EM calorimeter
     $\mu$: muon chambers
   - $\pi/K$ separation
     → Cerenkov device

4. Vertexing (measure $t_{\text{sig}} - t_{\text{tag}}$)
   → Silicon trackers
<e^+e^- B-factory accelerators>

\[ e^+e^- \rightarrow \gamma 4S \rightarrow B^0 \bar{B}^0 \text{ or } B^+B^- \]

**Symmetric energies (CESR)**

\[ E_{e^-} = E_{e^+} = \frac{M_{\gamma 4S}}{2} = 5.29 \text{GeV} \]

**Asymmetric energies (PEP-II, KEK-B)**

\[ \begin{align*}
E_{e^-} & \quad E_{e^+} \\
\end{align*} \]

\[ \gamma 4S \text{ (and } B \text{’s)} \text{ is moving in the lab frame.} \]

\[ \rightarrow B \text{ decay time measurements} \]

\[ E_{CM} = 2 \sqrt{E_{e^+}E_{e^-}} = M_{\gamma 4S} \]

\[ \begin{align*}
E_{\gamma 4S} &= E_{e^-} + E_{e^+} \\
P_{\gamma 4S} &= E_{e^-} - E_{e^+} \\
\end{align*} \]

\[ \rightarrow \quad \beta_{\gamma 4S} = \frac{P_{\gamma 4S}}{E_{\gamma 4S}} = \frac{E_{e^-} - E_{e^+}}{E_{e^-} + E_{e^+}} \]
**Beam separation**

Want collision to occur only at one location

→ Need for beam separation
   (avoid parasitic crossings)

**CESR**: Pretzel orbit
   Interweaving $e^+e^-$ orbits within a single ring
   Crossing angle $= \pm 2.3$ mrad

**PEP-II**: Separation by bending magnet

$$E_{e^+} \neq E_{e^-}$$

→ $e^+, e^-$ beams bend differently
   Head-on collision

**KEK-B**: Finite-angle crossing
   Crossing angle $= \pm 11$ mrad

Large crossing angle

→ Beam instability
   Luminosity reduction (geometrical)
   Looks OK for now.
**Crab crossing** *(KEK-B)*

In case finite-angle crossing causes problems

- **Without crab cavities**

- **With crab cavities**

  → complete overlap of beams
  (No geometrical luminosity loss. Suppresses beam-beam instability)
PEP-II (SLAC)
KEK-B (KEK, Japan)
<table>
<thead>
<tr>
<th>machine</th>
<th>CESR</th>
<th>PEP-II</th>
<th>KEK-B</th>
</tr>
</thead>
<tbody>
<tr>
<td>detector</td>
<td>CLEO</td>
<td>BaBar</td>
<td>Belle</td>
</tr>
<tr>
<td>circumference (km)</td>
<td>0.768</td>
<td>2.199</td>
<td>3.016</td>
</tr>
<tr>
<td># of rings</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>$E_{e^+}$ (GeV)</td>
<td>5.3</td>
<td>3.1</td>
<td>3.5</td>
</tr>
<tr>
<td>$E_{e^-}$ (GeV)</td>
<td>5.3</td>
<td>9.0</td>
<td>8.0</td>
</tr>
<tr>
<td>$\beta_{\tau S}$</td>
<td>$\sim 0$</td>
<td>0.49</td>
<td>0.39</td>
</tr>
<tr>
<td>$\delta E/E$</td>
<td>$6 \times 10^{-4}$</td>
<td>$7 \times 10^{-4}$</td>
<td>$7 \times 10^{-4}$</td>
</tr>
<tr>
<td>$\Delta t_{\text{bunch}}$</td>
<td>$14 ns$</td>
<td>$4.2 ns$</td>
<td>$2 ns$</td>
</tr>
<tr>
<td>bunch size ($w$)</td>
<td>500 $\mu$m</td>
<td>181 $\mu$m</td>
<td>77 $\mu$m</td>
</tr>
<tr>
<td>&quot; (h)</td>
<td>10 $\mu$m</td>
<td>5.4 $\mu$m</td>
<td>1.9 $\mu$m</td>
</tr>
<tr>
<td>&quot; (l)</td>
<td>1.8 cm</td>
<td>1.0 cm</td>
<td>0.4 cm</td>
</tr>
<tr>
<td>crossing angle (mrad)</td>
<td>±2.3</td>
<td>0</td>
<td>±11</td>
</tr>
<tr>
<td>Luminosity ($cm^{-2} s^{-1}$)</td>
<td>$1.5 \times 10^{33}$</td>
<td>$3 \times 10^{33}$</td>
<td>$10 \times 10^{33}$</td>
</tr>
<tr>
<td>$# B\bar{B}/s$</td>
<td>1.5</td>
<td>3</td>
<td>10</td>
</tr>
</tbody>
</table>

achievements so far

| Lum(peak) | $8 \times 10^{32}$ | $15 \times 10^{32}$ | $10.5 \times 10^{32}$ |
| $\int Ldt$ (fb$^{-1}$) | 9.2 | 1.7 | 0.72 |
### Benchmarks

<table>
<thead>
<tr>
<th>Year</th>
<th>BaBar Events</th>
<th>Belle Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>97</td>
<td>6/16 HER stored</td>
<td>7/16 LER stored</td>
</tr>
<tr>
<td>98</td>
<td>7/23 1st collision</td>
<td>12/11 HER stored</td>
</tr>
<tr>
<td>99</td>
<td>5/10 BaBar installed, 5/26 1st event recorded</td>
<td>1/13 LER stored, 2/5 1st collision</td>
</tr>
<tr>
<td>00</td>
<td>9/13 $&gt;10^{33}/\text{cm}^2\text{s}$</td>
<td>2/18 $&gt;10^{33}/\text{cm}^2\text{s}$</td>
</tr>
</tbody>
</table>
Luminosity

Daily Recorded Luminosity

BELLE

Luminosity (pb$^{-1}$)

Date

BaBar

Luminosity (pb$^{-1}$)

Date
Problems and Issues

Belle

1. Synchrotron radiation (SR) background
   - Readout chips (VA1) of Innermost SVD started to die.
     * Traced to SR from steering magnets ($E_c < 10$ keV).
     * Put 20$\mu$m-thick Au foil around the Be pipe. (Be pipe was ‘bare’ before)
     * Cover VA1’s with 300$\mu$m-thick Au.
     * Replaced SVD1.0 with SVD1.2 (‘spare’). (Summer 1999)
   - Excess hits in CDC.
     * Probably the backscattering from downstream HER.
     * Replaced the suspect beampipe (Al → Cu).
   - No SR background is noticeable at present. (i.e. the bkg is dominated by lost particle)
2. Vacuum leaks and other glitches.
   - BPM near IP leak - fixed.
   - Movable mask leak - being redesigned. (arcs and heating)
   - Magnet coil burn out.

   These typically cost 1~2 weeks each.

3. Current issues
   - Blowup of LER vertical beamsize.
     * $\sigma_y \rightarrow \times 2$ at 350 ma.
     * Suspect: SR-induced photoelectrons (or ECE - electron cloud effect)
       * Permanent magnets around beampipe did not have a dramatic effect.
   - Crab cavity.
     * 1st full prototype in 2000.
Problems and Issues

BaBar

1. Vacuum leak at SR mask.
   - At Cu-SS joint.
   - Replaced.

2. Beam background
   - Dominated by lost-particle.
   - Extrapolation: SVT limit at 30 fb^{-1}.
   - Will improve with time (bake-out)
   - Not compromising data taking for now.
Belle Detector

1. Silicon Vertex Detector (SVD)
   3 layers of double sided silicon sensors
2. Central Drift Chamber (CDC)
   50 anode layers (18 stereo), 3 cathode layers
3. Aerogel Cherenkov Counter (ACC)
   960+228 cells, $n = 1.01 - 1.03$
4. Time Of Flight Counter (TOF)
   4cm thick scintillator, 128 $\phi$-segmentation

5. Electromagnetic Calorimeter (ECL)
   6624+1152+960 CsI(Tl) crystals
6. KL and Muon Detector (KLM)
   14 layers of glass RPC in iron yoke
7. Superconducting Solenoid
   1.5 Tesla
8. Extreme Forward Calorimeter (EFC)
   320 BGO crystals attached on the final focus quad.
The BaBar Detector

- Silicon Vertex Tracker
- Drift Chamber
- CsI Calorimeter
- DIRC Pid
- DIRC Stand-off Box
- Flux Return RPC
- Superconducting Coil
- e^+ (9 GeV)
- e^- (3.1 GeV)
Physics Performaances

\[ B \rightarrow J/\psi X \]

\[ m(\mu^+\mu^-) \]

$B A B A R$

\[ m(e^+e^-) \]

$J/\psi \rightarrow \mu^+\mu^-$

$J/\psi \rightarrow e^+e^-$
**Belle: J/ψ in μμ/ee channels**

Dimuons

Yield: $235 \pm 17$

Width: $13.6 \pm 1.0$ MeV/c$^2$

**Gaussian fit**

Dielectrons

"Crystal Ball" line shape
**Vertexing: Belle**

Matching eff. = 97% (Bhabha) / 96.7% for hadron

- **Δz resolution from** $J/\psi \rightarrow l^+l^-$
  - 138 μm

**Graph:**
- **Entries**
- **ΔZ** between di-leptons from $J/\Psi$ (cm)
- **Single Gauss**
  - Sig(data) = 137.9 μm
  - Sig(MC) = 111.2 μm
<Full reconstruction on \( \gamma 4S \)>

\[ B \rightarrow f_1 \cdots f_n \]

**Energy and absolute momentum** of \( B \) in the \( \gamma 4S \) frame are known:

\[ E_B = E_{\text{beam}} = 5.290 \text{ GeV} \]

\[ |\vec{P}_B| = \sqrt{E_{\text{beam}}^2 - M_B^2} = 0.34 \text{ GeV/c} \]

→**Move to the \( \gamma 4S \) rest frame** and require that candidates satisfy

\[ E_{\text{tot}} = E_{\text{beam}}, \quad |\vec{P}_{\text{tot}}| = |\vec{P}_B| \]

where

\[ E_{\text{tot}} \equiv \sum_{i=1}^{n} E_i, \quad \vec{P}_{\text{tot}} \equiv \sum_{i=1}^{n} \vec{P}_i \]

Instead of \( E_{\text{tot}} \) and \( |\vec{P}_{\text{tot}}| \), we often use

\[ \Delta E \equiv E_{\text{tot}} - E_B \quad \text{(energy difference)} \]

\[ M_{\text{bc}} \equiv \sqrt{E_{\text{beam}}^2 - \vec{P}_{\text{tot}}^2} \quad \text{(beam-constrained mass)} \]
$B \rightarrow J/\psi \ K^+$ channel

22 ± 6 events

*Belle Very Preliminary*
$B \to J/\psi K_S$ channel

Number of candidates in 440 pb data:

$B^0 \to J/\psi K_S$  5
$B^0 \to J/\psi K_L$  6
$B^0 \to \psi' K_S$  2
$B^0 \to J/\psi K^{*0}$  10
$B^+ \to J/\psi K^+$  22

Belle Very Preliminary

5 events in the signal box
A $B^0 \rightarrow J/\psi K_S$ candidate.
BaBar $B \rightarrow J/\psi K^{0,+}$

$B^+ \rightarrow J/\psi K^+$

$B^0 \rightarrow J/\psi K_S$
$D$ reconstruction (with help of PID devices): Belle

$D^0$ reconstruction in BELLE Data

$M = 1861$ MeV
$\sigma = 7.5$ MeV

$D^+$ reconstruction in BELLE Data

$M = 1866$ MeV
$\sigma = 6.6$ MeV
$D^0 / D^+$ lifetime measurement - vertex reconstruction in x-y: Belle

The lifetime is calculated from flight distance of $D^0$ from IP in the x-y plane.
(using run-by-run IP profile)

$\tau(D^0) = 405.2^{+10.2}_{-10.1} \text{ fs (stat.)}$
(PDG98: $\tau = 415 \pm 4 \text{ fs}$)

$D^+$ selection with $D^* \rightarrow D^+\pi^0$ tag to gain S/N.

$\tau(D^+) = 0.97 \pm 0.08 \text{ (stat.) ps}$
(PDG98: $\tau = 1.057 \pm 0.015\text{ps}$)

$D$ from charm production (not $b$) to avoid $b$ lifetime effect.
$(2.5 < p_{cm}^D < 5.3 \text{ GeV})$
BaBar $D^0$ lifetime

Candidate $D^0 \to k\pi$ proper decay time (ps)
BaBar $D^{*+} \rightarrow D^0 \pi_s^+, D^0 \rightarrow K^- \pi^+$

Effect of IP constraint for $\pi_s^+$

Before refit
$\sigma_1 = 354$ keV (27%)
$\sigma_2 = 908$ keV (73%)

After refit
$\sigma_1 = 280$ keV (47%)
$\sigma_2 = 679$ keV (53%)
Test of Kaon ID with $D^*$

\[ D^{*+} \rightarrow D^0 \pi^+ \]

\[ \rightarrow K^- \pi^+ \]

- $|M(D) - 1.865| \leq 0.030$
- $P(D^*)/Eb(CM) > 0.5$
- $|\cos \theta_k| \leq 0.8$
- reject if K-p inversed comb in the D mass window
  \[ \Rightarrow \text{Estimated purity} \sim 95\% \]
Belle data

Three modes combined

$B^\rightarrow D^0\pi^-$ combined

$78 \pm 10$ events

Three modes combined

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

$D^0 \rightarrow K^-\pi^+$

$D^0 \rightarrow K^-\pi^+\pi^0$

$D^0 \rightarrow K^-\pi^+\pi^-\pi^+$
$$B^± → D^0π^- + \text{c.c.}$$

$$D^0 → K^-\pi^+ + \text{c.c.}$$

$$B^0 → D^-\pi^+ + \text{c.c.: Belle}$$

$$B^0 → D^*-\pi^- + \text{c.c.: Belle}$$

$$B^- → D^0\pi^- + \text{c.c.}$$

$$D^0 → K^-\pi^+\pi^0 + \text{c.c.}$$

$$B^- → D^*0\pi^- + \text{c.c.: Belle}$$

$$B^- → D^0\pi^- + \text{c.c.}$$

$$D^0 → K^-\pi^+\pi^- + \text{c.c.}$$

$$B^0 → D^*0\pi^+ + \text{c.c.: Belle}$$

$$B^0 → D^*+\pi^- + \text{c.c.: Belle}$$
BaBar $B^0 \rightarrow D^* \ell^+ \nu$
Test of flavor tagging: Belle

Algorithm

**Lepton tag:** high $p^\text{c.m.}$ (> 1.1 GeV) lepton to tag $b \rightarrow c l \nu$ decay, and if it fails,

**Kaon tag:** charge sum of the charged Kaons to tag $b \rightarrow c \rightarrow s$ decay

Performance check

Use $B^0 \rightarrow D^{(*)-} l^+ \nu$ decay sample as CP side, remaining particles as tagging side.

~200 events

<table>
<thead>
<tr>
<th></th>
<th>$\varepsilon$(%)</th>
<th>wrong tag(%)</th>
<th>effective $\varepsilon$(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lepton tag</td>
<td>8 ± 1 (11.9)</td>
<td>1 ± 10 (8.2)</td>
<td>7 ± 3 (8.3)</td>
</tr>
<tr>
<td>Kaon tag</td>
<td>31 ± 3 (28.2)</td>
<td>21 ± 7 (15.2)</td>
<td>10 ± 5 (13.7)</td>
</tr>
<tr>
<td>Sum</td>
<td>40 ± 3 (40.1)</td>
<td>18 ± 6 (13.1)</td>
<td>16 ± 6 (21.8)</td>
</tr>
</tbody>
</table>

(): Monte Carlo estimation
Belle: B lifetime & mixing

Lifetime fit:
Fixed parameters:
\( \beta \gamma = 0.425 \)
\( x_d = 0.723 \)

\( c \tau = 484.0 \pm 20.6 \mu \text{m} \)
\( (\tau = 1.61 \pm 0.069 \text{ ps}) \)
Belle: \( B \rightarrow K^* \gamma \) signal candidates

- \( B^0 \rightarrow K^{*0} \gamma \)
- \( B^+ \rightarrow K^{*+} \gamma \)
- \( B^+ \rightarrow K^{*+} \gamma \)

10 candidates, 2 background expected.
Summary

- Both PEP-II and KEK-B exceeded $L = 10^{33}/\text{cm}^2\text{s}$, and are operating steadily.

- Integrated luminosity of $5\sim10 \text{ fb}^{-1}$ by this summer for each detector is realistic.

- Components of both detectors are functioning reasonably well.

- Beam backgrounds are more or less under control.

- If no major obstacles occur, $\sigma_{\sin2\beta}$ of $0.2\sim0.3$ is expected by this summer from each experiment.

Acknowledgement: Thanks to all at KEK/Belle and SLAC/BaBar who made so much progress and also to Nakao-san whose Belle physics plots I borrowed with minor editings.