La Belle Epoque: A Midterm Report

Particle Physics Seminar
Cornell University

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Princeton University
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Talk Outline

• Introduction
• KEK-B & Belle
• Mixing
• Indirect CP Violation Measurement/Analysis
  – Gold plated mode
  – Other $\sin 2\varphi_1$ Modes
• $B^0 \rightarrow \pi^+ \pi^-$
• $B \rightarrow K(\ast) ll$
The Kobayashi-Maskawa Mixing Scheme

Quark mixing is described via

\[
M = \begin{bmatrix}
V_{ud} & V_{us} & V_{ub} \\
V_{cd} & V_{cs} & V_{cb} \\
V_{td} & V_{ts} & V_{tb}
\end{bmatrix} \approx \begin{bmatrix}
1 - \lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\
-\lambda & 1 - \lambda^2/2 & A\lambda^2 \\
A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1
\end{bmatrix}
\]

Where the second matrix is the Wolfenstein parameterization.

The “d b” unitarity relation yields

\[V_{ud}V_{td} + V_{us}V_{ts} + V_{ub}V_{tb} = 0\]

\[V_{td} + V_{ub}^* \approx A\lambda^3\]
The gold-plated mode determines the angle $\phi_1$ which is also called $\beta$.
asymmetric $e^+e^-$ collider

• Two separate rings
  
  $e^+$ (LER) : 3.5 GeV
  
  $e^-$ (HER) : 8.0 GeV

• $E_{\text{CM}}$ : 10.58 GeV at $\Upsilon(4S)$

• Luminosity

  • target: $10^{34}$ cm$^{-2}$s$^{-1}$
  
  • achieved: $7.2\times10^{33}$cm$^{-2}$s$^{-1}$

• $\pm 11$ mrad crossing angle

• Small beam sizes:

  $\sigma_y \approx 3 \ \mu m$; $\sigma_x \approx 100 \ \mu m$
Machine Performance

Integrated/day

Summer shutdowns

Total Integrated

~80 fb⁻¹

Reported here

~80 fb⁻¹
## KEKB/PEP II Luminosity Bakeoff

<table>
<thead>
<tr>
<th></th>
<th>KEKB</th>
<th>PEP-II</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Peak</strong></td>
<td>$7.2 \times 10^{33}$ cm$^{-2}$s$^{-1}$</td>
<td>$4.6 \times 10^{33}$ cm$^{-2}$s$^{-1}$</td>
</tr>
<tr>
<td><strong>Shift</strong></td>
<td>140 pb$^{-1}$</td>
<td>105 pb$^{-1}$</td>
</tr>
<tr>
<td><strong>24 hour</strong></td>
<td>385 pb$^{-1}$</td>
<td>303 pb$^{-1}$</td>
</tr>
<tr>
<td><strong>7 day</strong></td>
<td>2207 pb$^{-1}$</td>
<td>1789 pb$^{-1}$</td>
</tr>
<tr>
<td><strong>Integrated</strong></td>
<td>93.3 fb$^{-1}$</td>
<td>92.5 fb$^{-1}$</td>
</tr>
</tbody>
</table>

As of ~Sept. 30, 2002    Comparisons not quite apples to apples.
Belle Detector

- SC solenoid 1.5T
- CsI(Tl) 16$X_0$
- TOF counter

Aerogel Cherenkov cnt.
$n = 1.015 \sim 1.030$

3.5GeV $e^+$

8GeV $e^-$

Tracking + $dE/dx$
small cell + He/$C_2H_5$

Si vtx. det.
3 lyr. DSSD

$\mu / K_L$ detection
14/15 lyr. RPC+Fe
The BELLE Collaboration

An international collaboration involving about 10 Countries, 50 Institutes, & 250 People

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Neutral B’s exhibit the fascinating phenomenon of mixing, which is where we will start the story.
Flavor Tagging

As noted, in IDCPV measurements, one needs to know the flavor of the spectator $B^0$. This information can also be used for mixing studies.

- **Track level tags**
  - High momentum leptons
  - Medium momentum $K^\pm$
  - High-momentum $\pi^\pm$ (from e.g., $B^0 \rightarrow D^{(*)-}\pi^+$)
  - Low-momentum $\pi^\pm$ (from D*’s).
- Need to take into account multiple tags and correlations.
Flavor Tagging: “Hamlet”

$q = \pm 1; \quad 0 < r < 1 \iff \text{tag reliability}$
Mixing measurements can be done by counting “same-sign” decays or by observing the timing distributions, or both.
Mixing

There are various ways to determine the flavor of the decaying $B^0$. In one method, one side of the event is fully reconstructed using known hadronic decay modes, such as $B^0 \rightarrow D^{*-}\pi^+$ and the other side is tagged using standard flavor tagging algorithm. Timing distributions are then plotted for same-flavor (SF) and opposite-flavor (OF) subsamples.
The effect of the mixing is readily evident when the asymmetry is plotted as a function of $\Delta t$. 
# Summary of Mixing Results

<table>
<thead>
<tr>
<th>Method</th>
<th>Signal</th>
<th>Tag</th>
<th>$\Delta m_d (\text{ps}^{-1})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dilepton</td>
<td>$B^0 \rightarrow D^* \pi^+$</td>
<td>High-$p_t l^\pm$</td>
<td>$0.503 \pm 0.008 \pm 0.009$</td>
</tr>
<tr>
<td></td>
<td>$D^* \rightarrow D^0 \pi$</td>
<td>High-$p_t l^\pm$</td>
<td></td>
</tr>
<tr>
<td>Semi-leptonic</td>
<td>$B^0 \rightarrow D^* l^+\nu$</td>
<td>Hamlet</td>
<td>$0.494 \pm 0.012 \pm 0.015$</td>
</tr>
<tr>
<td>Partial</td>
<td>$B^0 \rightarrow D^* l^+\nu$</td>
<td>High-$p_t l^\pm$</td>
<td>$0.505 \pm 0.017 \pm 0.020$</td>
</tr>
<tr>
<td>reconstruction</td>
<td>$D^* \rightarrow D^0 l^+\nu$</td>
<td>High-$p_t l^\pm$</td>
<td></td>
</tr>
<tr>
<td>Hadronic</td>
<td>$B^0 \rightarrow D^* l^+\nu$</td>
<td>Hamlet</td>
<td>$0.528 \pm 0.017 \pm 0.011$</td>
</tr>
</tbody>
</table>
But What About the CP Violating Phase?

\[ |B^0(t)\rangle = e^{-i(m-i\Gamma)/2} \times \left[ \cos\left(\frac{\Delta m}{2}\right) |B^0\rangle + i \sin\left(\frac{\Delta m}{2}\right) e^{-2i\phi_m} |\overline{B}^0\rangle \right] \]

As noted, it is there, but we can’t get at it in a standard mixing measurement since it disappears when we “project out” the flavor eigenstates.

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Indirect CP Violation

\[ |B^0(t)\rangle \propto \left[ \cos\left(\frac{\Delta m t}{2}\right) |B^0\rangle + i e^{-2i\phi_1} \sin\left(\frac{\Delta m t}{2}\right) |\bar{B}^0\rangle \right] \]

\[ |\bar{B}^0(t)\rangle \propto \left[ i e^{2i\phi_1} \sin\left(\frac{\Delta m t}{2}\right) |B^0\rangle + \cos\left(\frac{\Delta m t}{2}\right) |\bar{B}^0\rangle \right] \]

\[ |B^0_\pm\rangle \simeq \frac{1}{\sqrt{2}} \left[ |B^0\rangle \pm |\bar{B}^0\rangle \right] \quad \text{CP Eigenstates} \]

\[ B_0^- \rightarrow J / \Psi K_S \quad \text{CP odd} \]

\[ B_0^+ \rightarrow J / \Psi K_L \quad \text{CP even} \]
Indirect CP Violation

If we choose $\varphi_1 = 45^\circ$, then $e^{\pm 2i\varphi_1} = \pm i$

\[ |B^0(t)\rangle \propto \cos\left(\frac{\Delta m t}{2}\right) |B^0\rangle + \sin\left(\frac{\Delta m t}{2}\right) |\bar{B}^0\rangle \]

\[ |\bar{B}^0(t)\rangle \propto -\sin\left(\frac{\Delta m t}{2}\right) |B^0\rangle + \cos\left(\frac{\Delta m t}{2}\right) |\bar{B}^0\rangle \]
Indirect CP Violation

\[ \Gamma(t) = e^{-t/\tau_B} \left[ 1 \pm \xi_f \sin(\Delta m t) \sin 2\phi \right] \]

CP eigenvalue

Interference from mixing.
The Measurement

Need to:
- Measure momenta
- ID leptons & K’s
- Measure vertices
Analysis Flowchart

1. CP mode reconstruction
   - Signal / Background

2. Flavor Tagging of other B
   - Wrong tag Fraction

3. Vertex reconstruction
   - $\Delta t = \Delta z/c\beta\gamma$, Resol.Func.

4. CP fit
   - $\sin 2\phi_1$
Muon Identification

The dilepton decay modes are a big part of the reason of why the “gold-plated” modes are given that name.

\[ B^+ \rightarrow J / \Psi K^+ \]
\[ \rightarrow \mu^+ \mu^- K^+ \]

plus tag-side \( \mu \)

The gaps are instrumented with RPCs.
J/Ψ Reconstruction

• Require one lepton to be positively identified and the other to be consistent with lepton hypothesis.

• For $e^+e^-$, add any photon within .05 of electron direction.

- Dimuons
  - Yield: 28160. ± 345.
  - Mean: 3096.1 ± 0.1 MeV/c²
  - Width: 9.6 ± 0.1 MeV/c²

- Dielectrons
  - Yield: 24000. ± 287.
  - Mean: 3094.1 ± 0.1 MeV/c²
  - Width: 10.8 ± 0.2 MeV/c²

29 fb⁻¹
B Reconstruction

\(J/\psi \ K_s(\pi^+\pi^-)\)

457 Events
\(~3\% \) Background

29 fb\(^{-1}\) sample

\[\Delta E \equiv E_{\text{cand}}^* - E_{\text{beam}}^*\]

\[m_{bc} = \sqrt{\left(E_{\text{beam}}^*\right)^2 - \left(\sum_{\text{cand}} \vec{p}\right)^2}\]

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\( \Psi' \) Modes

\[ \psi' \rightarrow l^+ l^- \quad \psi' \rightarrow J/\psi \pi \pi \]

Both leptons tagged.

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Other Charmonium Modes

29 fb⁻¹ sample

1st observation of inclusive $B \rightarrow \chi_{c2} X$

$\chi_{c1}$ Yield: 2270. ± 85
$\chi_{c1}$ Mean: 413.6 MeV/c² (Fixed)
$\chi_{c1}$ Width: 7.2 MeV/c² (Fixed)
$\chi_{c2}$ Yield: 553. ± 67
$\chi_{c2}$ Mean: 460.0 MeV/c² (Fixed)
$\chi_{c2}$ Width: 7.9 MeV/c² (Fixed)
CP Even Mode ($B^0 \to J/\Psi K_L$) Reconstruction

- **Assume** $B^0 \to J/\Psi K_L$ (2-body) kinematics.
- Look for $K_L$ recoiling from $J/\psi$
  - hits in RPCs
  - cluster in ECL
- Remove positively tagged background modes: $J/\psi K^+$, $J/\psi K^*$, etc.
- Plot $p_B^* = |\vec{p}_{J/\Psi}^* + \vec{p}_{K_L}^*|$

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\[ p_B^* = \left| \vec{p}_{J/\Psi}^* + \vec{p}_{K_L}^* \right| \]

**78 fb^{-1} Sample**

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## Charmonium CP Mode Summary

<table>
<thead>
<tr>
<th>Mode</th>
<th>$\xi_f$</th>
<th>$N_{rec}$</th>
<th>Purity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$J/\psi(\ell^+\ell^-)K^0_S(\pi^+\pi^-)$</td>
<td>$-1$</td>
<td>1285</td>
<td>0.98</td>
</tr>
<tr>
<td>$J/\psi(\ell^+\ell^-)K^0_S(\pi^0\pi^0)$</td>
<td>$-1$</td>
<td>188</td>
<td>0.82</td>
</tr>
<tr>
<td>$\psi(2S)(\ell^+\ell^-)K^0_S(\pi^+\pi^-)$</td>
<td>$-1$</td>
<td>91</td>
<td>0.96</td>
</tr>
<tr>
<td>$\psi(2S)(J/\psi\pi^+\pi^-)K^0_S(\pi^+\pi^-)$</td>
<td>$-1$</td>
<td>112</td>
<td>0.91</td>
</tr>
<tr>
<td>$\chi_{c1}(J/\psi\gamma)K^0_S(\pi^+\pi^-)$</td>
<td>$-1$</td>
<td>77</td>
<td>0.96</td>
</tr>
<tr>
<td>$\eta_c(K^0_SK^-\pi^+)K^0_S(\pi^+\pi^-)$</td>
<td>$-1$</td>
<td>72</td>
<td>0.65</td>
</tr>
<tr>
<td>$\eta_c(K^+K^-\pi^0)K^0_S(\pi^+\pi^-)$</td>
<td>$-1$</td>
<td>49</td>
<td>0.72</td>
</tr>
<tr>
<td>$\eta_c(\rho\bar{\rho})K^0_S(\pi^+\pi^-)$</td>
<td>$-1$</td>
<td>21</td>
<td>0.94</td>
</tr>
<tr>
<td><strong>All with $\xi_f = -1$</strong></td>
<td></td>
<td>1895</td>
<td>0.94</td>
</tr>
<tr>
<td>$J/\psi(\ell^+\ell^-)K^{*0}(K^0_S\pi^0)$</td>
<td>$-1(19%)/+1(81%)$</td>
<td>101</td>
<td>0.92</td>
</tr>
<tr>
<td>$J/\psi(\ell^+\ell^-)K^0_L$</td>
<td>$+1$</td>
<td>1330</td>
<td>0.63</td>
</tr>
<tr>
<td><strong>All</strong></td>
<td></td>
<td>3326</td>
<td>0.81</td>
</tr>
</tbody>
</table>

78 fb$^{-1}$ Sample
Flavor Tagging

Two measures of tagging performance:

- $\varepsilon = \text{efficiency}$
- $w = \text{wrong-tag fraction}$
- $r = 1 - 2w$

Amplitude of mixing oscillation depends on $w$

$$\varepsilon_{\text{eff}} = 0.27 \pm 0.01$$
The B lifetime is of the same order as the vertex resolution, so the effect is quite subtle.
Effect of Resolution

The resulting signature of CP violation is mainly a mean shift between the $B^0$ and $\bar{B}^0$ samples.
Test of Vertex Resolution

$B^0 \rightarrow J / \Psi K^{*0}$

$K^-\pi^+$
(take as tag-side Vtx)

$l^+l^-$ (CP Vtx)

\[ r.m.s. = 123\mu m \]
\[ \sigma = 97.1\pm4.8\mu m \]
Fitting

$$P_{\text{sig}}(\Delta t) = \frac{e^{-|\Delta t|/\tau_B}}{2\tau_B} \left[1 - \xi_f q(1 - 2w) \sin 2\varphi_1 \sin(\Delta m \Delta t)\right]$$

Signal

$$P_{\text{bkg}}(\Delta t) = f_\tau \frac{e^{-|\Delta t|/\tau_{bg}}}{2\tau_{bg}} + (1 - f_\tau)\delta(\Delta t)$$

Background

$$L_i = P_{\text{sig}}(\Delta t' - \Delta t) \otimes R_{\text{sig}}(\Delta t) \times (1 - f_{\text{bg}})$$

Response function

$$+ P_{\text{bkg}}(\Delta t' - \Delta t) \otimes R_{\text{bg}}(\Delta t) \times f_{\text{bg}}$$

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The Fitted Result: 78 fb\(^{-1}\) Sample

\[
\sin 2\varphi_1 = 0.719 \pm 0.074 \pm 0.035
\]

cf BaBar \sin 2\beta = 0.741 \pm 0.067 \pm 0.033
Time-Dependent Asymmetry

One can plot the excess/deficit on a bin-by-bin basis. The plots to the right are not corrected for dilution effects (wrong tagging, background, etc.).

78 fb$^{-1}$ Sample
# Subsample Dependence

<table>
<thead>
<tr>
<th>Sample</th>
<th>$N_{ev}$</th>
<th>$\sin 2\phi_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$J/\psi K^0_S(\pi^+\pi^-)$</td>
<td>1116</td>
<td>$0.73 \pm 0.10$</td>
</tr>
<tr>
<td>$(\bar{c}\bar{c})K^0_S$ except $J/\psi K^0_S(\pi^+\pi^-)$</td>
<td>523</td>
<td>$0.67 \pm 0.17$</td>
</tr>
<tr>
<td>$J/\psi K^0_L$</td>
<td>1230</td>
<td>$0.78 \pm 0.17$</td>
</tr>
<tr>
<td>$J/\psi K^{*0}(K^0_S\pi^0)$</td>
<td>89</td>
<td>$0.04 \pm 0.63$</td>
</tr>
<tr>
<td>$f_{tag} = B^0 (q = +1)$</td>
<td>1465</td>
<td>$0.65 \pm 0.12$</td>
</tr>
<tr>
<td>$f_{tag} = \bar{B}^0 (q = -1)$</td>
<td>1493</td>
<td>$0.77 \pm 0.09$</td>
</tr>
<tr>
<td>$0 &lt; r \leq 0.5$</td>
<td>1600</td>
<td>$1.26 \pm 0.36$</td>
</tr>
<tr>
<td>$0.5 &lt; r \leq 0.75$</td>
<td>658</td>
<td>$0.62 \pm 0.15$</td>
</tr>
<tr>
<td>$0.75 &lt; r \leq 1$</td>
<td>700</td>
<td>$0.72 \pm 0.09$</td>
</tr>
<tr>
<td>All</td>
<td>2958</td>
<td>$0.72 \pm 0.07$</td>
</tr>
</tbody>
</table>
What if $|\lambda| \neq 1$?

In general we have

$$p_{\pm}(\Delta t) = \frac{\Gamma e^{-\Gamma |\Delta t|}}{2(1 + |\lambda|^2)} \left[ \frac{1 + |\lambda|^2}{2} \pm \text{Im} \lambda \sin(\Delta m \Delta t) + \frac{1 - |\lambda|^2}{2} \cos(\Delta m \Delta t) \right]$$

If $|\lambda|$ is allowed to float, (i.e. a $\cos(\Delta m t)$ term)

$$|\lambda| = 0.950 \pm 0.049 \pm 0.026$$

$$\sin 2\phi_1 = 0.720 \pm 0.074$$

The CPV asymmetry is ~unchanged.

Note: if $|\lambda| \neq 1$, then the gold-plated mode isn’t really gold plated.

78 fb$^{-1}$ Sample
Other $\phi_1$ Modes $b \rightarrow s\bar{s}s$

In the SM, the phase for these decays is $\sim 0$, so the IDCPV asymmetry should be $\sim \sin 2\phi_1$ and no direct CPV. Given the anomalously large rate, however, there might be more to the story . . .

$B(B^0 \rightarrow \eta' K^0) = 5.8 \times 10^{-5}$
Other $\phi_1$ Modes $b \rightarrow s \bar{s} s s$

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

$B^0 \rightarrow \eta' K_S$

$\pi^+ \pi^- \eta, \rho \gamma$

$B^0 \rightarrow \phi K_S$

$\pi^+ \pi^-$

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

$B^0 \rightarrow K^+ K^- K_S$

$(K^+ K^- \neq \phi)$

$M_{bc}$ (GeV/$c^2$)

$M_{bc}$ (GeV/$c^2$)

$M_{bc}$ (GeV/$c^2$)
Other $\phi_1$ Modes: $b \rightarrow s\bar{s}s$

Raw Asymmetries

$B \rightarrow \eta' K_S$

$B \rightarrow \phi K_S$

$B \rightarrow K^+ K^- K_S$

Uncertainty in CP ± fractions

$w = (3 \, +16 \, )\%$

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Other $\varphi_1$ Modes: $b \rightarrow c\bar{c}d$

\[ B^0 \rightarrow J/\psi \pi^0 \]
\[ B^0 \rightarrow J/\psi \rho^0 \]

\[ \mathcal{B}(B^0 \rightarrow J/\psi \pi^0) = (1.8 \pm 0.3 \text{(stat)} \pm 0.2 \text{(syst)}) \times 10^{-5} \]
\[ \mathcal{B}(B^0 \rightarrow J/\psi \eta) < 1.4 \times 10^{-5} \text{ (at 90\% C.L.)} \]
\[ \mathcal{B}(B^0 \rightarrow J/\psi \rho^0) = (2.8 \pm 0.5 \text{(stat)} \pm 0.7 \text{(syst)}) \times 10^{-5} \]
Other $\varphi_1$ Modes: $b \rightarrow c\bar{c}d$

78 fb$^{-1}$ Sample

$-S_{J/\Psi \pi} = 0.93 \pm 0.49 \pm 0.08$

$A_{J/\Psi \pi} = -0.25 \pm 0.39 \pm 0.06$
Measuring $2\phi_2 = 2(\pi - \phi_1 - \phi_3)$

for $f = \pi^+ \pi^-$

$$A_{CP}(\Delta t) = \frac{\Gamma(B^0 \rightarrow f) - \Gamma(\bar{B}^0 \rightarrow f)}{\Gamma(B^0 \rightarrow f) + \Gamma(\bar{B}^0 \rightarrow f)}$$

$$= -\xi_f \sin(\Delta m \Delta t) \sin 2(\phi_M + \phi_D)$$

$$= -\xi_f \sin(\Delta m \Delta t) \sin 2(\phi_1 + \phi_3)$$

With just one amplitude, CP violating phases will remain hidden. With two, they are revealed in a simple way. Three, alas, is not even better.

Ideal Case
Measuring $2\phi_2$

\[ \begin{array}{c}
\bar{b} \rightarrow \bar{d} \rightarrow \bar{u} \rightarrow u \rightarrow \pi^+ \\
B^0 \\
d \rightarrow d \rightarrow \pi^- \\
B^0 \\
\end{array} \]

\[ \begin{array}{c}
\bar{b} \rightarrow \bar{d} \rightarrow \bar{u} \rightarrow u \rightarrow \pi^+ \\
B^0 \\
V_{td} \\
d \rightarrow d \rightarrow \pi^- \\
B^0 \\
\end{array} \]

$B \rightarrow \pi^+ \pi^-$ decay

Interference between the tree level and penguin decay graphs is a little bit too much of a good thing!
B → π⁺π⁻ decay

\[ \Gamma(\Delta t) = \frac{e^{-\Delta t/\tau_B}}{\tau_B} \left[ 1 \pm \xi_f (S_{\pi\pi} \sin \Delta m \Delta t + C_{\pi\pi} \cos \Delta m \Delta t ) \right] \]

Mean shift between q=+1 and q=-1 samples.

Population difference between the q=+1 and q=-1 samples.
B→π⁺π⁻ decay

After cut on $M_{bc}$

The background situation is more difficult.
In the 42 fb$^{-1}$ sample, we have observed an asymmetry in the rate for $B^0 \rightarrow \pi^+\pi^-$ vs. $\bar{B}^0 \rightarrow \pi^+\pi^-$. At present, this is only a $\sim3\sigma$ effect, but if it persists with higher statistics, it will represent the first observation of direct CP violation in the B system.

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$\Gamma(\Delta t) = \frac{e^{-\Delta t / \tau_B}}{\tau_B} \left[ 1 \pm \xi_f \left( S_{\pi\pi} \sin \Delta m\Delta t + C_{\pi\pi} \cos \Delta m\Delta t \right) \right]$
\[ B \rightarrow K^{(*)} l^+ l^- \]

FCNC decays like \[ B \rightarrow K^{(*)} l^+ l^- \] have a long and important history in particle physics. In the SM, they are forbidden at the tree level, but occur through penguins and loops, which are potentially sensitive to beyond-the-SM contributions.

60 fb\(^{-1}\) Sample
**B \rightarrow K^{(*)} l^+ l^-**

\[ BR(B \rightarrow K \ell^+ \ell^-) = (0.58 \pm 0.16 \pm 0.06) \times 10^{-6} \]

\[ BR(B \rightarrow K^* \ell^+ \ell^-) < 1.4 \times 10^{-6} \text{ 90\% C.L.} \]

Both results consistent with SM expectations.

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Future Prospects

Projection of Luminosity Accumulation

1/fb

Oide

33/fb
75/fb
130/fb
315/fb
440/fb

Installation of Ante-chambers and Crab cavities and Energy switch

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Summary & Conclusions

• CP violation in the B system has been observed at the >6σ level.

\[ \sin 2\varphi_1 = 0.719 \pm 0.074 \pm 0.035 \]

• We see an indication of CP violation in \( B \rightarrow \pi^+\pi^- \) decay.

• The KEKB accelerator is working very well and now holds the world record for instantaneous and integrated luminosity.

• There will be lots of good physics to come.
Additional Slides
B→π⁺π⁻ Checks

- Asymmetry for Kπ:

- Fitted values for various control samples:

<table>
<thead>
<tr>
<th></th>
<th>K⁺π⁻</th>
<th>D⁺π⁻</th>
<th>D*⁺π⁻</th>
<th>D*⁺ρ⁻</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\tau_B) (ps)</td>
<td>1.73 ± 0.15</td>
<td>1.64 ± 0.05</td>
<td>1.61 ± 0.05</td>
<td>1.68 ± 0.06</td>
</tr>
<tr>
<td>S</td>
<td>0.15 ± 0.24</td>
<td>0.09 ± 0.09</td>
<td>0.13 ± 0.09</td>
<td>−0.04 ± 0.10</td>
</tr>
<tr>
<td>C̀</td>
<td>0.07 ± 0.17</td>
<td>0.01 ± 0.06</td>
<td>−0.03 ± 0.06</td>
<td>−0.10 ± 0.07</td>
</tr>
</tbody>
</table>
Likelihood Plots

-2\ln(L/L_{max}) vs. \sin 2\phi_1

- \xi_f = -1
- \xi_f = +1
- all modes
$K_L^0$ Detection

\[ P_{\text{miss}} = P_{4S} - \sum_{i=\gamma, h^\pm} P_i \]

Inclusive “$K_L$’s”

October 4, 2002
Vertexing

- Common track requirements
  - # of associated SVD hits > 2
  - Use run-dependent IP
- For CP-side, use $J/\psi \rightarrow l^+l^-$ tracks
  - Reject poorly fit events.
- For Tag-side, use tracks with:
  - $|\delta z|<1.8\text{mm}$, $|\sigma_z|<500\ \mu\text{m}$, $|\delta r|<500\ \mu\text{m}$
  - Iterate: discard worst track until fit is acceptable.
- Require $|z_{CP} - z_{tag}|<2\ \text{mm}$ ($\approx 10\tau_B$)
Test of Vertex Resolution

\[ B^0 \rightarrow J/\Psi K^{*0} \]

K^-\pi^+
(take as tag-side Vtx)

\( l^+l^- \) (CP Vtx)

\[ \text{r.m.s.}=123\mu m \]
\[ \sigma=97.1\pm4.8\mu m \]
The first order effect is a mean shift between positively and negatively tagged samples (Summer ’01 sample).
Sources of Systematic Error

<table>
<thead>
<tr>
<th>Source</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertex algorithm</td>
<td>±0.022</td>
</tr>
<tr>
<td>Flavor tagging</td>
<td>±0.015</td>
</tr>
<tr>
<td>Resolution function</td>
<td>±0.014</td>
</tr>
<tr>
<td>$K_L$ background fraction</td>
<td>±0.010</td>
</tr>
<tr>
<td>Fit biases</td>
<td>±0.007</td>
</tr>
<tr>
<td>$\Delta m_d$ and $\tau_{B_0}$ errors</td>
<td>±0.007</td>
</tr>
<tr>
<td>Total</td>
<td>±0.035</td>
</tr>
</tbody>
</table>
Subsample Dependence

$r$ bin

- $0.875 - 1.000$
- $0.750 - 0.875$
- $0.500 - 0.750$
- $0.000 - 0.500$

$q_0 = +1$
(B$^-$-tag)

$q_0 = -1$
(B$^+$-tag)

All

\(\sin 2\phi_1\)

- $0.96^{+0.15}_{-0.17}$
- $1.54^{+0.24}_{-0.28}$
- $0.27 \pm 0.25$
- $-0.12^{+0.58}_{-0.57}$
- $0.60 \pm 0.19$
- $1.00^{+0.15}_{-0.16}$
- $0.82 \pm 0.12$
Comparison to other $\sin^2\phi_1$ Measurements

It looks like CDF had it right!