First
Physics Results from
Babar

David Hitlin
Caltech
for the BABAR Collaboration

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Osaka
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The **BABAR** Collaboration

**USA** [35/276]
- California Institute of Technology
- UC, Irvine
- UC, Los Angeles
- UC, San Diego
- UC, Santa Barbara
- UC, Santa Cruz
- U of Cincinnati
- U of Colorado
- Colorado State
- Florida A&M
- U of Iowa
- Iowa State U
- LBNL
- LLNL
- U of Louisville
- U of Maryland
- U of Massachusetts, Amherst
- MIT
- U of Mississippi
- Mount Holyoke College
- Northern Kentucky U
- U of Notre Dame
- ORNL/Y-12
- U of Oregon
- U of Pennsylvania
- Prairie View A&M
- Princeton
- SLAC
- U of South Carolina
- Stanford U
- U of Tennessee
- U of Texas at Dallas
- Vanderbilt
- U of Wisconsin
- Yale

**Canada** [4/16]
- U of British Columbia
- McGill U
- U de Montréal
- U of Victoria

**France** [5/50]
- LAPP, Annecy
- LAL Orsay
- LPNHE des Universités Paris 6/7
- Ecole Polytechnique
- CEA, DAPNIA, CE-Saclay

**Germany** [3/21]
- U Rostock
- Ruhr U Bochum
- Technische U Dresden

**Italy** [12/89]
- INFN, Bari
- INFN, Ferrara
- Lab. Nazionali di Frascati dell’ INFN
- INFN, Genova
- INFN, Milano
- INFN, Napoli
- INFN, Padova
- INFN, Pavia
- INF, Pisa
- INFN, Roma and U "La Sapienza"
- INFN, Torino
- INFN, Trieste

**Norway** [1/3]
- U of Bergen

**Russia** [1/13]
- Budker Institute, Novosibirsk

**United Kingdom** [10/80]
- U of Birmingham
- U of Bristol
- Brunel University
- U of Edinburgh
- U of Liverpool
- Imperial College
- Queen Mary & Westfield College
- Royal Holloway, University of London
- U of Manchester
- Rutherford Appleton Laboratory

**9 Countries**
**72 Institutions**
**554 Physicists**
Outline of the talk

- PEP-II and BABAR
- Selected measurements
  - $B$ lifetimes
  - $B$ mixing
  - $J/\psi K^*$ polarization
  - $\pi\pi, K\pi, KK$ branching ratios
- Measurement of $CP$-violating asymmetries in $B$ decays to $CP$ eigenstates
  - Isolating and tagging the $CP$ sample
  - Determining the $\Delta z$ resolution
  - Determining the mistag fractions
  - Determining the $CP$-violating asymmetries
- Conclusion
With the goal of measuring $CP$-violating asymmetries in $B^0$ meson decay, construction of the PEP-II asymmetric storage ring and the associated $BABAR$ detector were started in 1993 and 1994, respectively.

- PEP-II had first collisions in the Summer of 1998
- $BABAR$ was rolled onto the beamline in Spring 1999 and saw its first events on May 26, 1999
- PEP-II peak luminosity is $2.28 \times 10^{33}$ [3 x $10^{33}$ is design] using 606 bunches [1658 is design], with 1286 ma $e^+$ and 751 ma $e^-$

- PEP-II efficiency has been higher than expected and $BABAR$ efficiency has typically been $> 95\%$; the integrated “design day” luminosity of 135 pb$^{-1}$ (delivered) has been exceeded

- PEP-II has delivered 16 fb$^{-1}$ as of July 28
  - $BABAR$ has recorded 14.8 fb$^{-1}$
    - The results presented today are based on $\sim$10 fb$^{-1}$
    - Much of the early data requires reprocessing to improve calibration and alignment
PEP-II delivered/BABAR recorded luminosity 1999+2000

PEP-II delivered: 16.0 fb^{-1}
BABAR logged: 14.8 fb^{-1}

BABAR daily recorded luminosity

design day
**BABAR talks at ICHEP2000**

- **Parallel Sessions**
  - Study of inclusive and exclusive \( B \) decays to charmonium final states with **BABAR**.
    Gerhard Raven, UCSD
  - **BABAR** results on \( B \) decays to \( D^* \) and \( D_s \)\((^*)\).
    Gloria Vuagnin, Universita' di Trieste
  - Study of \( B \) lifetime and mixing with fully-reconstructed \( B^0 \) decays with **BABAR**.
    Fernando Martinez-Vidal, Univ. Paris VI et VII
  - **BABAR** results on \( B \) lifetime and mixing with partially-reconstructed \( B^0 \) decays.
    Christophe Yeche, Saclay
  - **BABAR** study of the decays \( B \rightarrow K^*\gamma \), \( B \rightarrow Kl^+l^-\) and \( B \rightarrow K^*l^+l^-\).
    Colin Jessop, SLAC
  - Study of charmless two-body, three-body and quasi-two-body \( B \) decays with **BABAR**.
    Theresa Champion, Univ. of Birmingham
  - **DIRC - The particle identification system for BABAR**.
    J. Schwiening, SLAC

- **Plenary Session**
  - First Physics Results from **BABAR**
    David Hitlin, Caltech
Dilepton Mixing: Results

7.7 fb\(^{-1}\) on-resonance
1.1 fb\(^{-1}\) off-resonance

\[ m_d = (0.507 \pm 0.015(\text{stat}) \pm 0.022(\text{syst})) \text{ h ps}^{-1} \]

[PDG: \(Dm_d = (0.472 \pm 0.017) \text{ h ps}^{-1}\)]

Dilepton sub-sample enriched in \(B^0\) with partial reconstruction of \(B^0 \cdot D^*l\)
Global likelihood fit using $m_{ES}$, $E$, Fisher discriminant, and Cherenkov angle measured in DIRC

<table>
<thead>
<tr>
<th>Mode</th>
<th>$N_s$</th>
<th>Stat. Sig. ($\sigma$)</th>
<th>$B$ ($10^{-6}$)</th>
<th>CLEO</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^+\pi^-$</td>
<td>$29^{+8+3}_{-7-4}$</td>
<td>5.7</td>
<td>$9.3^{+2.6+1.2}_{-2.3-1.4}$</td>
<td>$4.3^{+1.6}_{-1.4} \pm 0.5$</td>
</tr>
<tr>
<td>$K^+\pi^-$</td>
<td>$38^{+9+3}_{-8-5}$</td>
<td>6.7</td>
<td>$12.5^{+3.0+1.3}_{-2.6-1.7}$</td>
<td>$17.2^{+2.5}_{-2.4} \pm 1.2$</td>
</tr>
<tr>
<td>$K^+K^-$</td>
<td>$7^{+5}_{-4}$ ($&lt;15$)</td>
<td>2.1</td>
<td>$&lt;6.6$</td>
<td>$&lt;1.9$</td>
</tr>
</tbody>
</table>
Amplitude Analysis of $B \ J/\psi K^*$

| $|A|^2$  | $0.13 \pm 0.06 \pm 0.02$ |
|----------|--------------------------|
| $|A_0|^2$ | $0.60 \pm 0.06 \pm 0.04$ |
| $f_{||}$ | $2.58 \pm 0.39 \pm 0.20$ |
| $f$      | $0.01 \pm 0.27 \pm 0.10$ |

Will be used for future $\sin(2\beta)$ measurement.
The Wolfenstien parametrization of the CKM matrix

\[ \begin{align*}
\ell & \quad 1 - \frac{\rho^2}{2} & \quad 1 - \frac{\rho^2}{2} & \quad A_1^3 (r - i \eta) \\
\eta & \quad -1 & \quad 1 - \frac{\rho^2}{2} & \quad A_1^2 \\
\gamma & \quad A_1^3 (1 - r - i \eta) & \quad -A_1^2 & \quad 1 \\
\beta & \quad \gamma & \quad \beta & \quad \beta \\
\alpha & \quad \alpha & \quad \alpha & \quad \alpha \\
\end{align*} \]

1 and A are well-determined; \( \rho \) and \( \eta \) are not

The unitarity of the CKM matrix provides six constraints, the most useful of which

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

is called the unitarity triangle:

The area of the unitarity triangle, the “Jarlskog Invariant”, is proportional to the strength of \( CP \) violation in the Standard Model:
The sides of the unitarity triangle are determined by the magnitudes of the CKM matrix elements.

Uncertainties in theoretical models for $V_{ub}, f_B, B_K$, etc limit the determination of the triangle.

The $CP$ asymmetry in $B^0$ decays to $CP$ eigenstates measures

$$\sin 2\beta = -\arg\left[\frac{V_{ut}V_{ut}^*}{V_{ut}V_{tt}^*}\right]$$

allowing us to overdetermine the Unitarity Triangle.
Measuring $CP$ violation at the $\Upsilon(4S)$

The $\Upsilon(4S)$ resonance decays to $B\bar{B}$ pairs in a coherent $L=1$ state.

At PEP-II, with $e^{-}$ energy of 9 GeV and $e^{+}$ energy of 3.1 GeV, the $\Upsilon(4S)$ is produced with $\beta\gamma=0.56$.

The mean decay distance $\Delta z$ between the $B$ decay vertices is $\sim250$ $\mu$m, making it possible to ascertain the time order of the decays.

If we can measure the flavor of a $B^0(\bar{B}^0)$ decay ($B_{tag}$) occurring at a time $t$, then at that time, the flavor of the other $\bar{B}^0(B^0)$ is known.

We then reconstruct the decay of the second $B^0$ at a time $\Delta t=t-t_0$ into a $CP$ eigenstate:

$$f_{\pm}(\Delta t; \Gamma, \Delta m_d, D \sin 2\beta) = \frac{1}{4} \Gamma e^{-\Gamma |\Delta t|} \left[ 1 \pm D \sin 2\beta \times \sin \Delta m_d \Delta t \right]$$

where the dilution $D = (1 - 2w)$ is derived from the measured mistag fraction $w$. 
There are four time distributions

\[ f_+ : \quad B_{\text{tag}} = B, \quad \Delta t > 0 \]
\[ B_{\text{tag}} = B, \quad \Delta t < 0 \]
\[ f_- : \quad B_{\text{tag}} = \bar{B}, \quad \Delta t > 0 \]
\[ B_{\text{tag}} = \bar{B}, \quad \Delta t < 0 \]

The CP asymmetry is

\[ \mathcal{A}_{CP} = \frac{f_+ (\Delta t) - f_- (\Delta t)}{f_+ (\Delta t) + f_- (\Delta t)} = \mathcal{D} \sin 2\beta \times \sin \Delta m_s \Delta t \]
Overview of the analysis

Reconstruct the $B$ decays to $CP$ eigenstates and tag the flavor of the other $B$ decay

Select $B_{tag}$ events using, primarily, leptons and $K$'s from $B$ hadronic decays & determine $B$ flavor

Select $B_{CP}$ events ($B^{0} \rightarrow J/\psi K_{S}^{0}$, etc.)

Measure the mistag fractions $w_i$ and determine the dilutions $D_i = 1 - 2w_i$

Measure $\Delta z$ between $B_{CP}$ and $B_{tag}$ to determine the signed time difference $\Delta t$ between the decays

Determine the resolution function for $\Delta z$

$$\mathcal{R}(\Delta t; \hat{\Delta}) = \sum_{i=1}^{i=2} \frac{f_i}{\sigma_i \sqrt{2\pi}} \exp\left(-\frac{(\Delta t - \delta_i)^2}{2\sigma_i^2}\right)$$

$$\mathcal{F}_{\pm}(\Delta t; \Gamma_i, \Delta m_d, D \sin 2\beta, \hat{\Delta}) = f_{\pm}(\Delta t; \Gamma_i, \Delta m_d, D \sin 2\beta) \otimes \mathcal{R}(\Delta t; \hat{\Delta})$$

$$\mathcal{A}_{CP}(\Delta t) \propto \frac{\mathcal{F}_{+}(\Delta t) - \mathcal{F}_{-}(\Delta t)}{\mathcal{F}_{+}(\Delta t) + \mathcal{F}_{-}(\Delta t)} \propto D \sin 2\beta \times \sin \Delta m_d \Delta t$$
A tagged $B^0 \, J/\psi K^0_S$ event
The $B_{CP}$ sample

\[ J/\psi K_s^0 (K_s^0 \rightarrow \pi^+\pi^-) \]
124±12 events
purity 96%

\[ J/\psi K_s^0 (K_s^0 \rightarrow \pi^0\pi^0) \]
18±4 events
purity 91%

\[ \psi (2S) K_s^0 \]
27±6 events
purity 93%
The resolution function for $\Delta t$

The time resolution is dominated by the $z$ resolution of the tagging vertex.

The vertex resolution function is well-described by a five-parameter sum of two gaussians:

$$ R(\Delta t; \delta_i) = \sum_{i=1}^{2} \frac{f_i}{\sigma_i \sqrt{2\pi}} \exp\left(-\frac{(\Delta t - \delta_i)^2}{2\sigma_i^2}\right) $$

In the likelihood fits, we use event-by-event time resolution errors. We introduce two scale factors $S_1$ and $S_2$:

$$ \sigma_i = S_i \times \sigma_{\Delta t} $$

To account for $\sim 1\%$ of events with very large $\Delta z$ a third gaussian with a fixed width of 8ps, is included.

The parameters extracted from the fit are:

<table>
<thead>
<tr>
<th>parameter</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\delta_1$ (ps)</td>
<td>-0.20 - 0.06 from fit</td>
</tr>
<tr>
<td>$\delta_2$ (ps)</td>
<td>0 fixed</td>
</tr>
<tr>
<td>$f_1$ (%)</td>
<td>1.66 - 0.6 from fit</td>
</tr>
<tr>
<td>$f_2$ (%)</td>
<td>75 fixed</td>
</tr>
<tr>
<td>$f_3$ (%)</td>
<td>1.33 - 0.14 from fit</td>
</tr>
<tr>
<td>$S_1$</td>
<td>2.1 fixed</td>
</tr>
<tr>
<td>$S_2$</td>
<td>0 fixed</td>
</tr>
</tbody>
</table>
Particle ID and mis-ID

- **Electrons**
  - Efficiency vs. $p_{lab}$ [GeV/c]
  - $20^\circ < \theta < 140^\circ$
  - Electrons from bremsstrahlung, $\gamma \gamma \rightarrow e^+e^-$
  - Pions from $K^\pm$

- **Muons**
  - Efficiency vs. $p_{lab}$ [GeV/c]
  - $0.5 \text{ GeV/c} < p_{lab} < 4.5 \text{ GeV/c}$
  - Electrons from bremsstrahlung, $\gamma \gamma \rightarrow e^+e^-$
  - Pions from $K^\pm$

- **Kaons**
  - Efficiency vs. $p_{lab}$ [GeV/c]
  - Polar angle [deg]
  - Efficiency and misidentification for $17^\circ < \theta < 155^\circ$

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David Hitlin  ICHEP2000  July 31, 2000

**BaBar**  Babar™ and © L. de Brunhoff
Measurement of mistag fractions & $\Delta m_d$

- Mistag fractions and $\Delta m_d$ are directly measured
  
  - We use a large sample of events in which one $B^0$ candidate, called $B_{\text{rec}}$, is fully reconstructed in a flavor eigenstate mode
    
    - Hadronicsample: 2227 events
    - $D^-, \pi^+, D^-, \rho^+, D^-, a_1^+, D^-, \pi^+, D^- \rho^+, D^- a_1^+$
    - Semileptonic events: 7517 events $D^-, \ell^+ \nu_{\ell}$
  
  - We apply flavor-tagging algorithms to the rest of the event, which constitutes the potential $B_{\text{tag}}$

- Tagging categories:
  
  - Electron
  - Muon
  - Kaon
  - NT1
  - NT2

- We classify tagged events as mixed or unmixed, depending on whether the $B_{\text{tag}}$ is tagged with the same or the opposite flavor as the $B_{\text{rec}}$

- The time-dependent rate of mixing, which best exploits information at small values of $\Delta t = t_{\text{rec}} - t_{\text{tag}}$, is used to extract $w_i$ and $\Delta m_d$

- The time-integrated rate of mixed events in each tagging category:
  
  $\chi_i = \chi_d + (1 - 2\chi_d)w_i$

  where

  $\chi_d = \frac{x_d^2}{2(1 + x_d^2)}$, \quad $x_d = \frac{\Delta m_d}{\Gamma}$

is used as a cross check
### Measurement of mistag fractions & $\Delta m_d$

**Hadronic sample**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Final State</th>
<th>Yield</th>
<th>Purity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hadronic (neutral)</td>
<td>$D^*\pi^+$</td>
<td>622 ± 27</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>$D^*\rho^+$</td>
<td>419 ± 25</td>
<td>84</td>
</tr>
<tr>
<td></td>
<td>$D^*a_1^+$</td>
<td>239 ± 19</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td>$D^-\pi^+$</td>
<td>630 ± 26</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>$D^-\rho^+$</td>
<td>315 ± 20</td>
<td>84</td>
</tr>
<tr>
<td></td>
<td>$D^{*-}\pi^+$</td>
<td>225 ± 20</td>
<td>74</td>
</tr>
<tr>
<td>total</td>
<td></td>
<td>2438 ± 57</td>
<td>85</td>
</tr>
<tr>
<td>Hadronic (charged)</td>
<td>$\bar{D}^0\pi^+$</td>
<td>1755 ± 47</td>
<td>88</td>
</tr>
<tr>
<td></td>
<td>$\bar{D}^*\pi^+$</td>
<td>543 ± 27</td>
<td>89</td>
</tr>
<tr>
<td>total</td>
<td></td>
<td>2293 ± 54</td>
<td>88</td>
</tr>
</tbody>
</table>
Measurement of mistag fractions & $\Delta m_d$

## Semileptonic sample

<table>
<thead>
<tr>
<th>Sample</th>
<th>Final State</th>
<th>Yield</th>
<th>Purity(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semileptonic</td>
<td>$D^*l\nu$</td>
<td>$7517 \pm 104$</td>
<td>84</td>
</tr>
</tbody>
</table>

[Graphs showing distributions for leptons, kaons, NT1, and NT2 tags]
Measurement of $\Delta m_d$

**Signal region, all tags**

**Sideband region, all tags**
The time-dependence of mixed and unmixed events is

\[ h_\pm (\Delta t; \Gamma, \Delta m_d, \mathcal{D}) = \frac{1}{4} \Gamma e^{-r|\Delta t|} [1 \pm \mathcal{D} \times \cos \Delta m_d \Delta t] \]

This is convoluted with the \( \Delta z \) vertex resolution function

\[ \mathcal{H}_\pm (\Delta t; \Gamma, \Delta m_d, \mathcal{D}, \delta) = h_\pm (\Delta t; \Gamma, \Delta m_d, \mathcal{D}) \otimes R(\Delta t; \delta) \]

and used to form a likelihood function

\[ \ln L_M = \sum_i \left[ \sum_{\text{unmixed}} \ln \mathcal{H}_+ (t; \Gamma, \Delta m_d, \mathcal{D}_i, \delta) \right] \]

\[ \sum_{\text{mixed}} \ln \mathcal{H}_- (t; \Gamma, \Delta m_d, \mathcal{D}_i, \delta) \]

from which we extract \( w_i = (1 - D_i)/2 \) and \( \Delta m_d \)

The period of the mixing rate \( a(\Delta t) = \frac{N_{\text{unmix}}(\Delta t) - N_{\text{mix}}(\Delta t)}{N_{\text{unmix}}(\Delta t) + N_{\text{mix}}(\Delta t)} \)

yields \( \Delta m_d \)

The amplitude yields \( w_i \) for each tagging mode
Results of the tag/mix likelihood fit

<table>
<thead>
<tr>
<th>Parameter</th>
<th>hadronic Fit Value</th>
<th>$Q = c(1-2w)^2$</th>
<th>semileptonic Fit Value</th>
<th>$Q = c(1-2w)^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta m_d$ [$\text{ps}^{-1}$]</td>
<td>$0.516 \pm 0.031$</td>
<td>—</td>
<td>$0.508 \pm 0.020$</td>
<td>—</td>
</tr>
<tr>
<td>$w(\text{Lepton})$</td>
<td>$0.116 \pm 0.032$</td>
<td>$0.062$</td>
<td>$0.084 \pm 0.020$</td>
<td>$0.071$</td>
</tr>
<tr>
<td>$w(\text{Kaon})$</td>
<td>$0.196 \pm 0.021$</td>
<td>$0.136$</td>
<td>$0.199 \pm 0.016$</td>
<td>$0.133$</td>
</tr>
<tr>
<td>$w(\text{NT1})$</td>
<td>$0.135 \pm 0.035$</td>
<td>$0.064$</td>
<td>$0.210 \pm 0.028$</td>
<td>$0.066$</td>
</tr>
<tr>
<td>$w(\text{NT2})$</td>
<td>$0.314 \pm 0.037$</td>
<td>$0.023$</td>
<td>$0.361 \pm 0.025$</td>
<td>$0.013$</td>
</tr>
<tr>
<td>scale core, sig</td>
<td>$1.33 \pm 0.13$</td>
<td>—</td>
<td>$1.32 \pm 0.07$</td>
<td>—</td>
</tr>
<tr>
<td>$\delta_{\text{core, sig [ps]}}$</td>
<td>$-0.20 \pm 0.07$</td>
<td>—</td>
<td>$-0.25 \pm 0.04$</td>
<td>—</td>
</tr>
<tr>
<td>$f_{\text{ell}}$</td>
<td>$0.016 \pm 0.006$</td>
<td>—</td>
<td>$0.000 \pm 0.002$</td>
<td>—</td>
</tr>
</tbody>
</table>

$\sum_i Q_i = 0.285$  \hspace{1cm}  $\sum_i Q_i = 0.283$
## Tagged events and mistag fractions \( w_i \)

### Mistag fractions (likelihood method) from the hadronic sample

<table>
<thead>
<tr>
<th>Tagging Category</th>
<th>( \varepsilon ) (%)</th>
<th>( w ) (%)</th>
<th>( Q ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lepton</td>
<td>11.2 ± 0.5</td>
<td>9.6 ± 1.7 ± 1.3</td>
<td>7.3 ± 0.3</td>
</tr>
<tr>
<td>Kaon</td>
<td>36.7 ± 0.9</td>
<td>19.7 ± 1.3 ± 1.1</td>
<td>13.5 ± 0.3</td>
</tr>
<tr>
<td>NT1</td>
<td>11.7 ± 0.5</td>
<td>16.7 ± 2.2 ± 2.0</td>
<td>5.2 ± 0.2</td>
</tr>
<tr>
<td>NT2</td>
<td>16.6 ± 0.6</td>
<td>33.1 ± 2.1 ± 2.1</td>
<td>1.9 ± 0.1</td>
</tr>
<tr>
<td>all</td>
<td>76.7 ± 0.5</td>
<td></td>
<td>27.9 ± 0.5</td>
</tr>
</tbody>
</table>

The effective tagging efficiency is

\[
Q_i = \varepsilon_i (1 - 2 w_i)^2
\]

### Tagged events by decay mode and tagging category

<table>
<thead>
<tr>
<th>Tagging Category</th>
<th>( J/\psi K_S^0 )</th>
<th>( \psi(2S)K_S^0 )</th>
<th>CP sample (tagged)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( K_S^0 \rightarrow \pi^+\pi^- )</td>
<td>( K_S^0 \rightarrow \pi^0\pi^0 )</td>
<td>( K_S^0 \rightarrow \pi^+\pi^- )</td>
</tr>
<tr>
<td>Electron</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Muon</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Kaon</td>
<td>29</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>NT1</td>
<td>9</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>NT2</td>
<td>10</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td>35</td>
<td>85</td>
</tr>
</tbody>
</table>
Δm_d from the tag/mix likelihood fit

Hadronic decays

\[ m_d = 0.516 \pm 0.031 \text{ (stat)} \pm 0.018 \text{ (syst) } \text{ps}^{-1} \]

Semileptonic decays

\[ m_d = 0.508 \pm 0.020 \text{ (stat)} \pm 0.022 \text{ (syst) } \text{ps}^{-1} \]

Combined result

\[ m_d = 0.512 \pm 0.017 \text{ (stat)} \pm 0.022 \text{ (syst) } \text{ps}^{-1} \]

[PDG: \[ m_d = 0.472 \pm 0.017 \text{ ps}^{-1} \]]
### Systematic uncertainties in $\Delta m_d$ & $w_i$

#### Hadronic decays

<table>
<thead>
<tr>
<th>Source</th>
<th>$\Delta m_d$ [fs$^{-1}$]</th>
<th>Lepton</th>
<th>Kaon</th>
<th>NT1</th>
<th>NT2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta t$ Resolution</td>
<td>0.011</td>
<td>0.004</td>
<td>0.004</td>
<td>0.004</td>
<td>0.004</td>
</tr>
<tr>
<td>Background $\Delta t$</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
</tr>
<tr>
<td>Background Resolution</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
</tr>
<tr>
<td>Background Fractions</td>
<td>0.004</td>
<td>0.004</td>
<td>0.002</td>
<td>0.006</td>
<td>0.004</td>
</tr>
<tr>
<td>$B^0$ lifetime</td>
<td>0.005</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>$z$ scale</td>
<td>0.005</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>$z$ boost</td>
<td>0.003</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Monte Carlo Correction</td>
<td>$+0.013$</td>
<td>$-0.001$</td>
<td>0.000</td>
<td>$-0.010$</td>
<td>$-0.015$</td>
</tr>
<tr>
<td>Total Systematic Error</td>
<td>0.018</td>
<td>0.013</td>
<td>0.010</td>
<td>0.017</td>
<td>0.015</td>
</tr>
<tr>
<td>Statistical Error</td>
<td>0.031</td>
<td>0.032</td>
<td>0.021</td>
<td>0.035</td>
<td>0.037</td>
</tr>
<tr>
<td>Total Error</td>
<td>0.036</td>
<td>0.035</td>
<td>0.023</td>
<td>0.039</td>
<td>0.040</td>
</tr>
</tbody>
</table>

#### $D^{*}l\nu$ decays

<table>
<thead>
<tr>
<th>Source</th>
<th>$\Delta m_d$ [fs$^{-1}$]</th>
<th>Lepton</th>
<th>Kaon</th>
<th>NT1</th>
<th>NT2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta t$ Resolution</td>
<td>0.012</td>
<td>0.005</td>
<td>0.009</td>
<td>0.012</td>
<td>0.005</td>
</tr>
<tr>
<td>Background $\Delta t$</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
</tr>
<tr>
<td>Background Resolution</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
</tr>
<tr>
<td>Background Dilutions</td>
<td>0.006</td>
<td>0.008</td>
<td>0.013</td>
<td>0.026</td>
<td>0.031</td>
</tr>
<tr>
<td>Background Fractions</td>
<td>0.006</td>
<td>0.009</td>
<td>0.011</td>
<td>0.017</td>
<td>0.032</td>
</tr>
<tr>
<td>$B^+$ Backgrounds</td>
<td>0.010</td>
<td>0.009</td>
<td>0.010</td>
<td>0.004</td>
<td>0.003</td>
</tr>
<tr>
<td>$B^0$ lifetime</td>
<td>0.006</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>$z$ scale</td>
<td>0.005</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>$z$ boost</td>
<td>0.003</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Monte Carlo Correction</td>
<td>$+0.008$</td>
<td>$-0.010$</td>
<td>$-0.001$</td>
<td>$-0.002$</td>
<td>$-0.006$</td>
</tr>
<tr>
<td>Total Systematic Error</td>
<td>0.022</td>
<td>0.018</td>
<td>0.023</td>
<td>0.035</td>
<td>0.046</td>
</tr>
<tr>
<td>Statistical Error</td>
<td>0.020</td>
<td>0.020</td>
<td>0.016</td>
<td>0.028</td>
<td>0.025</td>
</tr>
<tr>
<td>Total Error</td>
<td>0.030</td>
<td>0.027</td>
<td>0.031</td>
<td>0.045</td>
<td>0.052</td>
</tr>
</tbody>
</table>
$B^0$ and $B^\pm$ lifetimes using fully reconstructed hadronic decays

Uses the same vertex fitting technique as the $CP$ analysis

- $B^0$: $2210 \pm 58$ events
- $B^\pm$: $2261 \pm 53$ events

$B^0 = 1.506 \pm 0.052$ (stat) $\pm 0.029$ (syst) ps

$B^+ = 1.602 \pm 0.049$ (stat) $\pm 0.035$ (syst) ps

$B^+/B^0 = 1.065 \pm 0.044$ (stat) $\pm 0.021$ (syst) ps

(PDG: $1.548 \pm 0.032$)

(PDG: $1.653 \pm 0.028$)

(PDG: $1.062 \pm 0.029$)
The sin2\(\beta\) analysis was done blind to eliminate experimenters’ bias
- The amplitude in the asymmetry \(A_{CP}(\Delta t)\) was hidden by arbitrarily flipping its sign and by adding an arbitrary offset
- The \(CP\) asymmetry in the \(\Delta t\) distribution was hidden by multiplying \(\Delta t\) by the sign of the tag and by adding an arbitrary offset
- The blinded approach allows systematic studies of tagging, vertex resolution and their correlations to be done while keeping the value of sin2\(\beta\) hidden
- The result was unblinded two weeks ago
Extracting $\sin 2\beta$

- The $\Delta t$ distribution of the tagged $CP$ eigenstate decays, which is analyzed using maximum likelihood to extract the asymmetry $A_{CP}(\Delta t)$

$B^0$ and $\bar{B}^0$ tags

![Graph showing $B^0$ and $\bar{B}^0$ tags]
Extracting $\sin 2\beta$

Results of the likelihood fit to the full sample and various subsamples

$$\sin 2\beta = 0.12 \pm 0.37 \text{ (stat)} \pm 0.09 \text{ (syst)}$$
sin$2\beta$ in different tagging categories
Extracting $\sin 2\beta$

$\sin 2\beta = 0.12 \pm 0.37$ (stat) $\pm 0.09$ (syst)

$\chi^2$ for the binned asymmetry and the likelihood fit is 9.2 for 7 df
Statistical error

- The probability of obtaining a $1\sigma$ statistical error of 0.37 with a sample of 120 tagged $CP$ eigenstate decays has been estimated by generating a large number of toy Monte Carlo experiments with a sample of this size.
  - The errors are distributed around 0.32, with a standard deviation of 0.03.
  - The probability of obtaining a statistical error larger than the one we observe is 5%.

- Using a set of full Monte Carlo simulated experiments with the same number of events we observe, we estimate that the probability of finding a lower value of the likelihood than our observed value is 20%.

Checks

$CP$ asymmetry of channels that should have none.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Apparent $CP$ asymmetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>hadronic charged</td>
<td>$0.03 \pm 0.07$</td>
</tr>
<tr>
<td>hadronic neutral</td>
<td>$-0.01 \pm 0.08$</td>
</tr>
<tr>
<td>$J/\psi \ K^+$</td>
<td>$0.13 \pm 0.14$</td>
</tr>
<tr>
<td>$J/\psi \ K^{*0}$ ($K^{*0} \rightarrow K^+\pi^-)$</td>
<td>$0.49 \pm 0.26$</td>
</tr>
</tbody>
</table>
Fit including direct $CP$ violation

\[ A_{CP} = \frac{D \sin 2\beta \sin \Delta m_d \Delta t + (1 - |\lambda_{CP}|^2) \cos \Delta m_d \Delta t}{1 + |\lambda_{CP}|^2} \]

\[ \sin 2\beta = 0.12 \pm 0.37 \quad \frac{1 - |\lambda_{CP}|^2}{1 + |\lambda_{CP}|^2} = 0.26 \pm 0.19 \]
Systematic uncertainties

Compute fractional systematic errors using the measured value of the asymmetry increased by 1\(\sigma\). Different contributions are added in quadrature.

<table>
<thead>
<tr>
<th>Source of uncertainty</th>
<th>Uncertainty on sin(2\beta)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\tau_{B^0})</td>
<td>0.012</td>
</tr>
<tr>
<td>(\Delta m_d)</td>
<td>0.015</td>
</tr>
<tr>
<td>(\Delta z) resolution for CP sample</td>
<td>0.019</td>
</tr>
<tr>
<td>Time resolution bias for CP sample</td>
<td>0.047</td>
</tr>
<tr>
<td>Measurement of mistag fraction</td>
<td>0.059</td>
</tr>
<tr>
<td>Different mistag fraction for CP and non CP samples</td>
<td>0.050</td>
</tr>
<tr>
<td>Different mistag fractions for (B^0) and (\bar{B}^0)</td>
<td>0.005</td>
</tr>
<tr>
<td>Background in CP sample</td>
<td>0.015</td>
</tr>
<tr>
<td>Total systematic uncertainty</td>
<td>0.091</td>
</tr>
</tbody>
</table>
Constraints on the Unitarity Triangle

The set of ellipses represents the allowed range of \((\bar{\rho}, \bar{\eta})\) based on our knowledge of the magnitudes of CKM matrix elements, for a set of typical values of model-dependent theoretical parameters:

### Experimental inputs

<table>
<thead>
<tr>
<th>measurement</th>
<th>central value</th>
<th>exp. error</th>
</tr>
</thead>
<tbody>
<tr>
<td>(</td>
<td>V_{cb}</td>
<td>)</td>
</tr>
<tr>
<td>(</td>
<td>V_{ub}</td>
<td>)</td>
</tr>
<tr>
<td>(\Delta m_{B_s} (ps)^{-1})</td>
<td>.472</td>
<td>.017</td>
</tr>
<tr>
<td>(\Delta m_{B_d}) from A (Moriond 2000)</td>
<td>2.271</td>
<td>.017</td>
</tr>
<tr>
<td>(</td>
<td>\varepsilon_K</td>
<td>(10^{-3}))</td>
</tr>
</tbody>
</table>

### Theoretical inputs

<table>
<thead>
<tr>
<th>Theoretical est.</th>
<th>lower bound</th>
<th>higher bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>(&lt;\frac{\varepsilon_K}{\lambda})</td>
<td>0.070</td>
<td>0.100</td>
</tr>
<tr>
<td>(f_{B_s}\sqrt{B_{B_s}})</td>
<td>0.185</td>
<td>0.255</td>
</tr>
<tr>
<td>(\xi_1^2)</td>
<td>1.14</td>
<td>1.46</td>
</tr>
<tr>
<td>(B_K)</td>
<td>0.72</td>
<td>0.98</td>
</tr>
</tbody>
</table>

\(\sin 2\beta = 0.12 \pm 0.37 \pm 0.09\) is NOT included in the fits.
PEP-II and $B_{ABAR}$ have had an exciting and productive first year, producing more than 15 fb$^{-1}$ in the $\Upsilon(4S)$ region and recording more than 14 fb$^{-1}$ In 9 fb$^{-1}$ we have reconstructed and tagged 120 decays of $B^0$ to CP eigenstates

\[
\sin 2\beta = 0.12 \pm 0.37 \text{(stat)} \pm 0.09 \text{(syst)}
\]

\[
\Delta m_d = 0.507 \pm 0.015 \pm 0.022 \quad \text{di-lepton}
\]

\[
\Delta m_d = 0.516 \pm 0.031 \pm 0.018 \quad \text{hadronic}
\]

\[
\Delta m_d = 0.508 \pm 0.020 \pm 0.022 \quad \text{semileptonic}
\]

With 8 fb$^{-1}$ analyzed at the $\Upsilon(4S)$

\[
B^0 = 1.506 \quad 0.052 \text{ (stat)} \quad 0.029 \text{ (syst) \, ps}
\]

\[
B^+ = 1.602 \quad 0.049 \text{ (stat)} \quad 0.035 \text{ (syst) \, ps}
\]

\[
\frac{B^+}{B^0} = 1.065 \quad 0.044 \text{ (stat)} \quad 0.021 \text{ (syst)}
\]

Measurements of $B(K^\ast\gamma)$, $B(\pi\pi)$, $B(K\pi)$, $B(KK)$, …

A wide variety of other results have been presented in parallel sessions and contributed papers

The PEP-II run has been extended to the end of October, with the goal of integrating 25 fb$^{-1}$

This should allow for a measurement of \(\sin 2\beta\) with interesting precision