The Elephant in the B Factory

An Asymmetric Fable

E.I. Rosenberg

September 29, 2000
Outline

• Review of CP Violation
• SM Constraints
• The B-factory
• The BaBar Detector
• Preliminary results (\(\sim 9 \text{ fb}^{-1}\))
• Status and outlook
The Discrete Symmetries

Parity (P) – inversion of space

\[ \Gamma(K^+ \rightarrow \mu_L^+ \nu_{\mu L}) = \Gamma(K^+ \rightarrow \mu_R^+ \nu_{\mu R}) \]

Charge Conjugation (C) – interchange of particle and antiparticle (inversion of strong charges)

\[ \Gamma(K^+ \rightarrow \mu_L^+ \nu_{\mu L}) = \Gamma(K^- \rightarrow \mu_L^- \nu_{\mu L}) \]

Time Reversal (T) – inversion of time

\[ \Gamma(K^+ \rightarrow \mu_L^+ \nu_{\mu L}) = \Gamma(\mu_L^+ \nu_{\mu L} \rightarrow K^+) \]
CP and CPT Symmetries

- P, C and T are all conserved by the strong and electromagnetic interactions.
- The weak interaction violates P and C, but conserves the combination CP (almost).

\[ \Gamma(K^+ \rightarrow \mu^+_L \nu_{\mu_L}) = \Gamma(K^- \rightarrow \mu^-_R \nu_{\mu_R}) \]

- The combination CPT is always conserved.
- \( \Rightarrow \) CPT conservation requires:

\[ \Gamma_{\text{total}}(K^+) = \Gamma_{\text{total}}(K^-) \]
\[ \Gamma_{\text{total}}(K^0) = \Gamma_{\text{total}}(K^{0*}) \]

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\[ m_{K^0} - m_{K^{0*}} < 10^{-18} \]
Types of CP Violation

• **Direct CP Violation:**

\[ \langle f | H | M \rangle \neq \langle f | H | M \rangle \quad (|A_r| \neq |A_r^-|) \]

search with neutral or charged states

• **CP Violation in mixing:** the neutral states mix -- mass (decaying) and strong interaction eigenstates are different.

\[ |M_L\rangle = p |M^0\rangle + q |M^0\rangle; \quad |M_L^-\rangle = p |M^0\rangle - q |M^0\rangle \]

• If \(|q| \neq |p|\), the mass eigenstates are not CP eigenstates

• **CP Violation in the interference between mixing and decay:**

\[ \lambda = \frac{q}{p} \frac{\bar{A}_{fcp}}{A_{fcp}}; \quad \lambda \neq 1 \]

\[ |\lambda_f| = 1; \text{ Im } \lambda_f \neq 0 \]
Experimental Observation of CP Violation

• 1964 First observation: \( \Gamma(K_L^0 \rightarrow \pi\pi) \neq 0 \)

Only observed for neutral kaons and described by three measurements all of which involve the quark transition \( s \rightarrow u \):

\[
\eta_{+-} = \frac{A(K_L^0 \rightarrow \pi^+\pi^-)}{A(K_S^0 \rightarrow \pi^+\pi^-)} = \varepsilon + \varepsilon' \\
\eta_{00} = \frac{A(K_L^0 \rightarrow \pi^0\pi^0)}{A(K_S^0 \rightarrow \pi^0\pi^0)} = \varepsilon - 2\varepsilon' \\
\delta = \frac{\Gamma(K_L^0 \rightarrow \pi^-l^+\nu) - \Gamma(K_L^0 \rightarrow \pi^+l^-\bar{\nu})}{\Gamma(K_L^0 \rightarrow \pi^-l^+\nu) + \Gamma(K_L^0 \rightarrow \pi^+l^-\bar{\nu})} = (0.327 \pm 0.012)\% \\
\]

\( q = \frac{1 - \varepsilon}{1 + \varepsilon} \)

\( |\eta_{+-}| \approx |\eta_{00}| \approx 2.3 \times 10^{-3} \)
CP Violation and the Matter Universe

- At early times, \( n_B = n_B \)

- At some stage in the evolution: CP violating and baryon number changing processes can occur so

\[
\frac{(n_B - n_B)}{(n_B + n_B)} \neq 0
\]

- universe is temporarily out of equilibrium

- a short time late B violating processes are no longer active

- \( B + \bar{B} \rightarrow n\gamma \) converts all the antibaryons and all but the excess baryons to photons so

\[
\frac{n_B - n_B}{n_B + n_B} \rightarrow \frac{n_B}{n}\gamma
\]
The flavor eigenstates of the quarks are not the weak interaction eigenstates—there are transitions between the families.

This mixing is described by the CKM Matrix. Where the three diagonal elements $V_{ud}$, $V_{cs}$, and $V_{tb} \approx 1$, family is almost a good quantum number.
Standard Model and CP (II)

• The CKM Matrix is unitary and in the case of three generations can be parameterized by three Euler angles and six phases. Five of the phases can be absorbed into the quark phases. One observable phase remains.

• THE IMAGINARY PART OF THE CKM MATRIX IS NECESSARY TO DESCRIBE CP VIOLATION

• All CP violating amplitudes in the SM are proportional to

\[ J_{\text{CP}} = |\text{Im} (V_{ij} V_{kl} V_{il}^* V_{kj}^*)|; \ i \neq k, \ j \neq l \]

Wolfenstein parameterization

\[
\begin{pmatrix}
1 - \frac{\lambda^2}{2} & \lambda & A \lambda^3 (\rho - i\eta) \\
-\lambda & 1 - \frac{\lambda^2}{2} & A \lambda^2 \\
A \lambda^3 (1 - \rho - i\eta) & -A \lambda^2 & 1
\end{pmatrix} + O(\lambda^4)
\]
In the Wolfenstein parameterization, the CP violating amplitude $J_{CP} \propto A^2 \lambda^6 \eta \approx O(10^{-4})$

<table>
<thead>
<tr>
<th>Meson</th>
<th>Dominant quark decays</th>
<th>Resonance width</th>
<th>CP violating effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K$</td>
<td>$s \rightarrow u$</td>
<td>$\propto \lambda^2 \times \text{p.s}$</td>
<td>$\propto A^2 \lambda^4 \eta$</td>
</tr>
<tr>
<td>$D$</td>
<td>$c \rightarrow s$</td>
<td>$\propto 1 \times \text{p.s}$</td>
<td>$\propto A^2 \lambda^6 \eta$</td>
</tr>
<tr>
<td>$B$</td>
<td>$b \rightarrow c$</td>
<td>$\propto A^2 \lambda^4 \times \text{p.s}$</td>
<td>$\propto \lambda^2 \eta$</td>
</tr>
</tbody>
</table>

$A, \lambda, \eta$ are all $< 1$; $\lambda = 0.02205 \pm 0.0018$

THE LARGEST EFFECTS ARE IN THE B SYSTEM
The CKM matrix represents rotations between the quark generations and so is unitary: $V V^* = 1$

There are six equations of the form $V_{ij} V_{ik}^* = 0$ ($j \neq k$) which can be represented as a closed triangle in the complex plane -- all of which have area $\frac{1}{2} J_{CP}$.

The most useful contains the most poorly known elements of the CKM matrix: $V_{ud} V_{ub}^* + V_{cd} V_{cb}^* + V_{td} V_{tb}^* = 0$
Physics Goals: Precision Measurement of the sides and angles of the CKM Unitarity Triangle to overconstrain the SM and look for new physics

At an asymmetric collider, such as PEP-II and KEK, we can measure the time-dependent CP-violating asymmetries in the decay of neutral B-mesons.

\[
\sin 2\beta: \quad B^0 \rightarrow J/\psi K^0_s, \quad B^0 \rightarrow J/\psi K^0_L, \quad B^0 \rightarrow J/\psi K^*(892) \\
B^0 \rightarrow D^+D^-, \quad B^0 \rightarrow D^{*+}D^-, \quad B^0 \rightarrow D^{*+}D^{*-}
\]

\[
\sin 2\alpha: \quad B^0 \rightarrow \pi^+\pi^-, \quad B^0 \rightarrow \rho\pi, \quad B^0 \rightarrow \rho\rho, \quad B^0 \rightarrow a_1\pi
\]
(difficult due to penguin contributions)

|V_{cb}| and |V_{ub}| using semileptonic decays

constrain $\gamma$

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BABAR Expected CKM Constraints

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Differences Bs and Ks

The neutral Ks:
\[ \Gamma(K_0^L) = 1.24 \times 10^{-8} \text{ s} \quad \Gamma(K_0^S) = 0.89 \times 10^{-10} \text{ s} \]

mass eigenstates have very different lifetimes
\[ \Delta m = 3.49 \times 10^{-12} \text{ MeV} \]
m = 497 MeV few final states are available

The neutral Bs:
\[ \Gamma(B_0^L) \approx \Gamma(B_0^H) \approx 1.28 \times 10^{-14} \text{ s} \]

we must work with strong eigenstates and need to tag the flavor of the B
\[ \Delta m = 3.05 \times 10^{-10} \text{ MeV} \]
m = 5280 MeV rich variety of final states to measure mixing and CP violation (but also more background)
B Flavor Tagging

In semileptonic decays -- the lepton charge “tags” the B flavor
One needs good lepton ID
CP Violation in the B sector using the asymmetry to a CP eigenstate

\[ a_{f_{cp}} = \frac{\Gamma(\bar{B}^0 \rightarrow f_{cp}) - \Gamma(B^0 \rightarrow f_{cp})}{\Gamma(B^0 \rightarrow f_{cp}) + \Gamma(\bar{B}^0 \rightarrow f_{cp})} \]

\[ a_{f_{cp}} = \frac{1 - |\lambda_{f_{cp}}|^2}{1 + |\lambda_{f_{cp}}|^2} \cos(\Delta m_B t) - 2 \text{Im} \lambda_{f_{cp}} \sin(\Delta m_B t) \]

if \( |\lambda| = 1 \); \( a_{f_{cp}} = -\text{Im} \lambda_{f_{cp}} \sin(\Delta m_B t) \)
The Golden Channel

\[ \lambda \left( B_d \rightarrow J/\psi K_s^0 \right) = - \begin{pmatrix} V_{tb}^* V_{td} \\ V_{tb} V_{td}^* \end{pmatrix} V_{cs}^* \begin{pmatrix} V_{cb} \\ V_{cb}^* \end{pmatrix} \begin{pmatrix} V_{cd}^* V_{cs} \\ V_{cd} V_{cs}^* \end{pmatrix} \]

B mixing \hspace{1cm} \text{Direct CP} \hspace{1cm} K \text{ Mixing}

\[ \text{Im} \lambda \left( B_d \rightarrow J/\psi K_s^0 \right) = \sin 2\beta \]
The PEP-II Collider Uses the 2-mile Long Linear Accelerator
# PEP-II Luminosity Performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Design</th>
<th>Achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminosity</td>
<td>cm(^{-2}) sec(^{-1})</td>
<td>3 \times 10^{33}</td>
<td>2.56 \times 10^{33}</td>
</tr>
<tr>
<td>Specific</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Luminosity cm(^{-2}) sec(^{-1}) mA(^{-2}) /bunch</td>
<td>3.1 \times 10^{30}</td>
<td>2.9 \times 10^{30}</td>
<td></td>
</tr>
<tr>
<td>Horizontal Spot Size (\mu m)</td>
<td>220</td>
<td>190</td>
<td></td>
</tr>
<tr>
<td>Vertical Spot Size (\mu m)</td>
<td>6.6</td>
<td>6.0</td>
<td></td>
</tr>
</tbody>
</table>

**PEP-II delivered 20 fb\(^{-1}\) from June 99 through Sept. 2000**

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B Decays at PEP-II

\[ L = 3 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1} \approx 30\text{fb}^{-1}\text{yr}^{-1} \]

At the \( \Upsilon_{4S} \) \( \sigma(e^+e^- \rightarrow b\bar{b}) = 1.05\text{nb} \)

\[ \Rightarrow N_{B\bar{B}}/\text{year} \approx 3 \times 10^7 \]

- Good Signal to Background: 1:4
- Only \( B_d \) and \( B_u \)
- Clean events \( <n_{\text{charged tracks}} > = 11 \)
- Kinematic constraints
- High efficiency for full reconstruction
Detector Requirements

To measure decay dependent asymmetries we need:

- Large uniform acceptance and high efficiency
- Precision vertex resolution
- High resolution particle tracking up to 4 GeV/c
- Identification of leptons and charged kaons
- Efficient, high resolution detection of neutral pions

BABAR uses:

- Asymmetric layout with a highly instrumented forward region
- Five layer Si strip detector with double sided readout
- 1.5T B-field and minimum multiple scattering drift chamber
- Segmented flux return ($\mu$), segmented CsI calorimeter (e), DIRC ($\pi$/K separation)
- CsI crystal calorimeter
The Detector

Si Vertex Tracker
Drift Chamber
CsI Electromagnetic Calorimeter
Particle ID -- DIRC
1.5 T Superconducting Coil
Iron Yoke with Resistive Plate Chambers for $\mu$ and $K^{0}_L$ ID
BABAR Is An International Collaboration
BaBar Recorded luminosity - 1999 + 2000

PEP dev=20.7/fb, BaBar log=19.4/fb

Friday, September 22, 2000

R. W. Kadel and Mike Sokoloff

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SVT and DCH are used to Reconstruct Charged Tracks

SVT: 5 layers
DCH: 40 layers

1.5 T solenoidal field

Typical values:

1. $0.41 < \theta < 2.54$ in lab fiducial angle
2. $\sigma_{\text{pt}/p_t} = 0.45\% + 0.14\% \times p_t$
3. Impact parameter resolution $\sim 60\mu \text{ @ 1 GeV/c}$. 
SVT - Silicon Vertex Tracker
SVT - Silicon Vertex Tracker

Five layers of double-sided Si 300 µm thick; rad hard
Gives (z,φ) coordinates

150k channels
\[ r = 3.2 \ldots 14 \text{ cm} \]
\[ \cos \theta_{\text{lab}} = -0.87 \ldots + 0.94 \]
readout pitch: 100 + 50 µm (inner)
210 + 100 µm (outer)

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Drift Chamber
7104 Signal Wires
40 layers
42...70 mrad Stereo angles
Gas:
He(80%) + iso-C₄H₁₀(20%)
Drift Chamber Resolution

All tracks reconstructed--mainly Bhabhas

Average cell resolution 125 μm

TDR resolution 140 μm
Detection of Internally Reflected Čerenkov Light

Particle ID by Čerenkov ring detection

12 boxes of 12 quartz bars each
11000 photomultipliers
DIRC Cerenkov Angle for tagged $\pi$'s and K's

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D0 Signal Improvement with DIRC PID

Momentum of D in $Y_{4s}$ rest frame $> 1.5$ GeV/c

Kaon momentum 0.5-4.0 GeV/c and point with quartz bar acceptance

Kaon Cerenkov angle within $2\sigma$
Electromagnetic Calorimeter

6580 CsI Crystals

\[ \cos \theta_{\text{lab}} = -0.77 \text{ to } 0.96 \]

\[ 90\% \, 4\pi \text{ in cm} \]

\[ \sigma_E/E = 1.33\% \cdot E^{-1/4} \oplus 2.1\% \]
Instrumented Flux Return

65 cm Fe
Resistive Plate Chambers inserted with area > 1000 m²
Cylindrical RPCs outside calorimeter

Gas:
Ar(48%) + C₂H₂F₄(48%) + isoC₄H₁₀(5%)

Maximum of 21 layers traversed
Calorimeter Performance

Generic B events with < 6 EMC clusters
Bkgd from combinatorics

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Lepton ID Efficiency

Babar

For $20^\circ < \theta < 140^\circ$

For $0.5 < p_{lab} (\text{GeV}/c) < 4.5$

For $17^\circ < \theta < 155^\circ$

For $1.5 < p_{lab} (\text{GeV}/c) < 3$

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Pion Rejection

$\pi/\mu$ Separation from DIRC  $\pi/e$ Separation from DCH

Sample of identified $\pi$'s from $K^0_s$ decays

$\theta_C$ (mrad)

Momentum (GeV/c$^2$)

$\pi$ $K$ $e$ $\mu$

$\pi/\mu$ Separation from DIRC

$\pi/e$ Separation from DCH
Computing: The Experiment
Within the Experiment

BaBar has chosen an Object Oriented Approach

• **Online (2.5 years from scratch)**
  C++ (written by novices in OO coding)
  Java (GUIs for histograms) ⇒ JAS

  CORBA

• **Offline**

  Reconstruction and analysis all C++
  Simulation moving to GEANT 4 (C++)

• **Data Storage (40 Tbytes thru April 2000)**

Objectivity database
L3 Trigger Event Display

Multihadron Event

Event: 10d939/56c49ad7

L3 T0=284.379ns
L1 AT0=0ns
MC T0=0ns

Delay: 1ms

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D0 Lifetime Measurement

Based on 800 pb⁻¹

\[ \tau_{D0} = 0.413 \pm 0.013 \text{(stat)} \pm 0.011 \text{(MC)} \pm 0.005 \text{(BKG)} \pm 0.005 \text{(BS)} \]

PDG98: .415±.004 ps
The red points are the data. The blue curve is a sum of a Gaussian, an exponential background. For the electron data, the blue curve also includes another exponential that describes the Bremsstrahlung tail.
B’s to Charmonium Final States

![Graphs showing B Mass and B_ch Mass distributions with BABAR data.](image)
1. With $e^-$ energy of 9 GeV and $e^+$ energy of 3.1 GeV, the $Y_{4s}$ is produced with $\beta\gamma=0.56$

$$\sigma(Y_{4s}) \sim 22\% \text{ of } \sigma(q\bar{q})$$

2. The $Y_{4s}$ resonance decays into $B\bar{B}$ pairs in a coherent $L=1$ state.

3. Tag one $B$, we know the flavor of the other $B$ at that time.

4. By having a Lorentz boost, the second $B$ decays at a later time and we have can study CP asymmetries as a function of time

$$f_\pm(\Delta t, \Gamma, \Delta m, D\sin2\beta) = \frac{1}{4} \Gamma e^{-\Gamma|\Delta t|} \left[ 1 \pm D\sin 2\beta \sin \Delta m\Delta t \right]$$

$D$ is a dilution factor, $D = (1-w)$, is related to the fraction of missed tag events, $w$. 
A Tagged $B \rightarrow J/\psi K^{0}_s$ Event
The $B_{CP}$ Sample

$J/\psi K^0_S (K^0_S \rightarrow \pi^+ \pi^-)$
124±12 events
purity 96%

$J/\psi K^0_S (K^0_S \rightarrow \pi^0 \pi^0)$
18±4 events
purity 91%

$\psi(2S) K^0_S$
27±6 events
purity 93%

$\Delta E = E^*_\text{reco} - E^*_\text{Beam}$ vs.

$m_{ES} = \sqrt{E^2_{\text{Beam}} - \vec{p}^2_{\text{reco}}}$
The Experimental Asymmetry

There are four time distributions:

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

\[ A_{CP} = \frac{f_+(\Delta t) - f_-(\Delta t)}{f_+(\Delta t) + f_-(\Delta t)} = D \sin 2\beta \sin(\Delta m \Delta t) \]
Precision on \( \sin(2\beta) \) measurement

Given by:

\[
\sigma_{\sin 2\beta} = \frac{\sigma(\sin 2\beta, \frac{\Delta m}{\Gamma}, \sigma_z)}{\sqrt{N_S} \sqrt{\varepsilon_{\text{tag}}(1 - 2\omega)^2}} \cdot \frac{\sqrt{1 + \frac{N_B}{N_S}}}{1 + (A_B/A_S) \left( \frac{N_B}{N_S} \right)}
\]

- \( \text{number of reconstructed signal events: } N_S; \)
- \( \text{number of background events: } N_B; \)
- \( \text{CP asymmetry of signal(background): } A_S(A_B); \)
- \( \text{\(\Delta z\) vertex resolution: } \sigma_z; \)
- \( \text{\(B\) mixing parameters: } \Delta m/\Gamma = 0.75; \)
- \( \text{tagging factor: } \varepsilon_{\text{tag}}(1-2\omega)^2; \)
- \( \text{coefficient: } \sigma(\sin 2\beta, \frac{\Delta m}{\Gamma}, \sigma_z) = \sigma_0 \)
**$B_d \rightarrow J/\psi K^0_S$ : the Golden Channel**

<table>
<thead>
<tr>
<th></th>
<th>$K^0_S \rightarrow \pi^+\pi^-$</th>
<th>$K^0_S \rightarrow \pi^0\pi^0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{Br}(B^0 \rightarrow J/\psi K^0_S)$</td>
<td>$4.25 \times 10^{-4}$</td>
<td></td>
</tr>
<tr>
<td>$\text{Br}(J/\psi \rightarrow l^+l^-)$</td>
<td></td>
<td>$0.12$</td>
</tr>
<tr>
<td>$\text{Br}(K^0_S \rightarrow \pi\pi)$</td>
<td>$0.686$</td>
<td>$0.314$</td>
</tr>
<tr>
<td>Reconstruction eff.</td>
<td>$0.60$</td>
<td>$0.21$</td>
</tr>
<tr>
<td># of rec signal events</td>
<td>$660$</td>
<td>$110$</td>
</tr>
<tr>
<td>$\varepsilon(1-2\omega)^2$</td>
<td></td>
<td>$0.3$</td>
</tr>
<tr>
<td>$N_B/N_s$</td>
<td>$0.06$</td>
<td>$0.06$</td>
</tr>
</tbody>
</table>

$\sigma(\sin2\beta) = 0.12$

($K^0_S \rightarrow \pi^+\pi^-$)

$\sigma(\sin2\beta) = 0.30$

($K^0_S \rightarrow \pi^0\pi^0$)
### CP reach for other $b \to c\bar{c}s$ decays

<table>
<thead>
<tr>
<th></th>
<th>$B^0 \to J/\psi K^0_L$</th>
<th>$B^0 \to \psi K^0_L$</th>
<th>$B^0 \to \chi_{c1} K^0_L$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Br(B^0 \to XK^0_L)$</td>
<td>$4.2 \times 10^{-4}$</td>
<td>$1.1 \times 10^{-4}$</td>
<td>$1.4 \times 10^{-4}$</td>
</tr>
<tr>
<td>$Br(J/\psi \to 1^+ 1^-)$</td>
<td></td>
<td></td>
<td>0.12</td>
</tr>
<tr>
<td>Reconstruction eff.</td>
<td>0.41</td>
<td>0.27</td>
<td>0.41</td>
</tr>
<tr>
<td># of rec signal events</td>
<td>650</td>
<td>120</td>
<td>140</td>
</tr>
<tr>
<td># of bckgrd events</td>
<td>380</td>
<td>100</td>
<td>110</td>
</tr>
<tr>
<td>$\Delta z$ resolution</td>
<td></td>
<td></td>
<td>130$\mu$m</td>
</tr>
<tr>
<td>$\sigma_0$</td>
<td></td>
<td></td>
<td>1.61</td>
</tr>
<tr>
<td>$\varepsilon_{tag}(1 - 2\omega)^2$</td>
<td></td>
<td></td>
<td>0.30</td>
</tr>
<tr>
<td>$\sigma(\sin 2\beta)$</td>
<td>0.14</td>
<td>0.31</td>
<td>0.27</td>
</tr>
</tbody>
</table>
The blinded approach allows systematic studies of tagging, vertex resolution and their correlations to be done while keeping the value of $\sin^2 \beta$ hidden

- The amplitude in the asymmetry, $A_{CP}(\Delta t)$, was hidden by arbitrarily flipping its sign and adding an 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 Experimental Distributions

Distributions for the tagged CP eigenstate decays of the B’s.

A likelihood fit is used to extract the asymmetry $A$.
Sin $2\beta$ from Likelihood Fit

$$\sin 2\beta = 0.12 \pm 0.37 \text{ (stat.)} \pm 0.09 \text{ (sys.)}$$
## Systematic Error on $\sin 2\beta$

<table>
<thead>
<tr>
<th>Source</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^0$ Lifetime</td>
<td>0.012</td>
</tr>
<tr>
<td>Mass Difference</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</td>
<td>0.005</td>
</tr>
<tr>
<td>Background in CP sample</td>
<td>0.015</td>
</tr>
<tr>
<td><strong>Total systematic uncertainty</strong></td>
<td><strong>0.091</strong></td>
</tr>
</tbody>
</table>
Sin 2\(\beta\) for the different tag categories

Identify flavor of \(B_{\text{tag}}\) using electrons or muons (\(p^*>1.1\) GeV/c), or charged kaons.

Or use neural net.

Charge of slow pion from \(D^*-\)

Lower momentum leptons;

\(p^*\) of charged particles
Asymmetry fits using $\sin 2\beta$
Results for channels that should have no CP asymmetry

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

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_{ud}</td>
<td>)</td>
</tr>
<tr>
<td>(</td>
<td>V_{us}</td>
<td>)</td>
</tr>
<tr>
<td>(\Delta m_{B_d} \quad (ps)^{-1})</td>
<td>.472</td>
<td>.017</td>
</tr>
<tr>
<td>(\Delta m_{B_s}) from (A) (Moriond 2000)</td>
<td>(\sigma_A)</td>
<td></td>
</tr>
<tr>
<td>(</td>
<td>\varepsilon_K</td>
<td>\quad (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{\alpha}{\pi})</td>
<td>0.070</td>
<td>0.100</td>
</tr>
<tr>
<td>(f_{B_d}\sqrt{B_{B_d}})</td>
<td>0.185</td>
<td>0.255</td>
</tr>
<tr>
<td>(\xi^*_d)</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>
Suppose we include direct CP violation

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

\[
\sin 2\beta = 0.12 \pm 0.37
\]

\[
\frac{1 - |\lambda|^2}{1 + |\lambda|^2} = 0.26 \pm 0.19
\]
Sin 2\(\beta\)
Osaka 2000

E. I. Rosenberg

September 29, 2000
Summary and Outlook

• PEP-II and BABAR have had an excellent first year
• First events May 16, 1999; preliminary results July, 2000 (9 fb\(^{-1}\))—more than just \(\sin 2\beta\) presented today
• We expect >25 fb\(^{-1}\) by the end of October and will rebblind the analysis
• Design luminosity almost here; will upgrade to \(3 \times 10^{34}\) over next five years.

THE FUN IS JUST STARTING