Measurement of $\sin 2\beta$

Claudio Campagnari
University of California, Santa Barbara
for the BaBar collaboration
Outline

• (Brief) theoretical overview
• How to measure $\sin 2\beta$
• PEP-II and BaBar performance
• $\sin 2\beta$ (and mixing) analysis
• Conclusions and future prospects
Why bother with all of this, or.. the most interesting questions in particle physics according to me!

- Quantum gravity, Plank scale and all of that
  - I have no idea how to address it experimentally, so I am not going to loose sleep over it
- Who ordered the muon?
- Origin of mass? (EWSB, Higgs, etc.)
- Origin of CP violation?
Why is CP violation in (my) top four?

• It is of fundamental importance
  – needed for matter-antimatter asymmetry in universe

• History tells us that studying symmetry violations can be very fruitful

• Conventional wisdom: SM CP-violation unlikely to explain universe asymmetry
  – It’s a good thing: it means that there is something beyond SM in CP violation somewhere, so a good place to work!
CP violation and the SM

- SM with three generation accommodates CP violation through phase in CKM matrix
- SM predicts a variety of CP violating asymmetries in the B-system, some of which can be cleanly interpreted in terms of CKM matrix elements (= parameters of the SM lagrangian)
- This is the main motivation to study CP violation in the B-system
Three kinds of CP-violation

• **CP violation in mixing**
  - tiny in the B-system because $\Delta \Gamma \ll \Delta M$

• **CP violation in decay**
  - requires interference between at least two amplitudes
  - amplitudes must have two phases, one that changes sign under CP (e.g. from CKM), and one that doesn’t (e.g. strong phase)
  - hard to understand theoretically
• **CP violation in the interference of mixing and decay**
  
  - in decays dominated by single amplitude, extraction of CKM elements is clean

\[ e^{i\pi} \text{ plays role of strong phase} \]

\[ e^{i\pi} \text{ changes sign} \]
This then leads to CP asymmetry:

\[
|A(B^0(t) \rightarrow f_{CP})|^2 \sim e^{-\Gamma t} \left[ 1 + \eta_{cp}(f) \sin(\Delta M t) \sin(2(\Phi_M - \Phi_D)) \right]
\]

\[
|A(B_0 \rightarrow f_{CP})|^2 \sim e^{-\Gamma t} \left[ 1 - \eta_{cp}(f) \sin(\Delta M t) \sin(2(\Phi_M - \Phi_D)) \right]
\]

\[
A_{CP} = \frac{|A(B^0(t) \rightarrow f_{CP})|^2 - |A(B^0(t) \rightarrow f_{CP})|^2}{|A(B^0(t) \rightarrow f_{CP})|^2 + |A(B^0(t) \rightarrow f_{CP})|^2}
\]

\[
A_{CP} = -\eta_{cp}(f) \sin(\Delta M t) \sin(2(\Phi_M - \Phi_D))
\]

\[
\eta_{cp} = \text{CP of final state}
\]

\[
\Gamma = \text{B width}
\]

\[
\Delta M = \text{mixing parameter}
\]

\[
\Phi_M = \text{CKM phase from mix}
\]

\[
\Phi_D = \text{CKM phase from decay}
\]
At the $\Upsilon(4S)$:

The $\Upsilon(4S)$ decays into a $P$-wave $B^0 \bar{B}^0$ state that evolves coherently till one of the $B$'s decays. The $B$'s are almost at rest in the $\Upsilon(4S)$ frame.

For a tag $B^0 (\bar{B}^0)$ at time $t_{\text{tag}}$, the time distribution of the other meson into a CP state at $\Delta t = t_{\text{CP}} - t_{\text{tag}}$ is given by

$$f \sim e^{-\Gamma|\Delta t|} [1 - \eta_{\text{cp}}(f) \sin(\Delta M \Delta t) \sin^2(\Phi_M - \Phi_D)]$$

$$f \sim e^{-\Gamma|\Delta t|} [1 + \eta_{\text{cp}}(f) \sin(\Delta M \Delta t) \sin^2(\Phi_M - \Phi_D)]$$

$A_{\text{CP}}$ integrates to zero over $\Delta t$.
CKM matrix unitarity: \[ V_{ud} V_{ub}^* + V_{cd} V_{cb}^* + V_{td} V_{tb}^* = 0 \]

\( A_{CP} \) in \( \Psi K_S \) measures \( \sin 2\beta \):
\[ \sin 2\beta = \sin 2(\Phi_M - \Phi_D) \]
The unitarity triangle (cont.)

- The sides are determined by measurements of the magnitudes of CKM elements
- $CP$ asymmetries to $f_{CP}$ measures angles of triangle
- In some cases, little or no theoretical ambiguities
- Goal of the B-physics program is to overconstrain triangle, critically test CKM structure of SM
Requirements for CP violation studies

• High statistics
  - $A_{CP}$ large, but BR small ($10^{-4}$ or less)

• At $\Upsilon(4S)$, need to measure $A_{CP}(\Delta t)$
  - Asymmetric beams
  - $\Delta t$ measured through $\Delta z \sim \gamma \beta c \Delta t$
    - typically 250 $\mu$m at BaBar

• Need to tag flavor by looking at decay products of the other $B$
  - use leptons and kaons (mostly)
The anatomy of a CP event

\[ \gamma(4S) \rightarrow B^0 (\bar{B}^0) \rightarrow J/\psi K^+ K^- \]

- \( \sigma_{\text{CP}} \approx 70 \mu m \)
- \( \sigma_{\text{tag}} \approx 180 \mu m \)

- \( B^0_{CP} \)
- \( J/\psi \)
- \( K^0_S \)
- \( e^+, e^- \)
- \( \pi^+ \)
- \( \pi^- \)
- \( e^{+(-)}, \mu^{+(-)}, K^{+(-)} \) tags

March 2, 2001

C. Campagnari - UCSB
PEP-II and BaBar - Timeline

- TDR and approval in 1995
- First collisions in Summer 1998
- Detector installed by April 1999
  - Missing a piece of the DIRC
- First collisions with BaBar May 1999
- Run to 09/99, complete DIRC 10/99
- Physics RUN 1: 11/99 to 10/00
- Integrated Luminosity: ~ 21 fb$^{-1}$ on peak
  - compare: CLEO grand total 9.1 fb$^{-1}$
BaBar efficiency: 94%

CESR/CLEO
PEP-II/BaBar

BaBar

PEP-II Delivered 23.7/fb
BABAR Recorded 22.2/fb

BaBar efficiency: 94%

March 2, 2001
C. Campagnari - UCSB
Efficiency by day

Daily integrated lumi

March 2, 2001  C. Campagnari - UCSB
PEP-II asymmetric B Factory

Achieved all major design goals:

<table>
<thead>
<tr>
<th>PEP-II parameters</th>
<th>Design</th>
<th>Typical (last year run)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy HER/LER</td>
<td>9.0/3.1</td>
<td>9.0/3.1</td>
</tr>
<tr>
<td>I HER/LER (mA)</td>
<td>0.75/2.15</td>
<td>0.7/1.3</td>
</tr>
<tr>
<td>#bunches</td>
<td>1658</td>
<td>553-829</td>
</tr>
<tr>
<td>bunch spacing (ns)</td>
<td>4.2</td>
<td>6.3-10.5</td>
</tr>
<tr>
<td>$\sigma_x$ ($\mu$m)</td>
<td>110</td>
<td>120</td>
</tr>
<tr>
<td>$\sigma_y$ ($\mu$m)</td>
<td>3.3</td>
<td>5.6</td>
</tr>
<tr>
<td>$\sigma_z$ (mm)</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Luminosity ($10^{33}$ cm$^{-2}$ s$^{-1}$)</td>
<td>3</td>
<td>2.5</td>
</tr>
<tr>
<td>$Ldt$ (pb$^{-1}$/day)</td>
<td>135</td>
<td>120</td>
</tr>
<tr>
<td>HE Beam Lifetime (h)</td>
<td>4 (@1A)</td>
<td>9 (@0.7A)</td>
</tr>
<tr>
<td>LE Beam Lifetime (h)</td>
<td>4 (@2A)</td>
<td>3 (@1.1A)</td>
</tr>
</tbody>
</table>

PEP-II reached a luminosity of $3.3 \times 10^{33}$ cm$^{-2}$ s$^{-1}$

Design is $3 \times 10^{33}$ cm$^{-2}$ s$^{-1}$
The BABAR Collaboration

9 Countries
72 Institutions
554 Physicist

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

China [1/6]
- Inst. of High Energy Physics, Beijing

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 and U Bari
- INFN and U Ferrara
- Lab. Nazionali di Frascati dell’ INFN
- INFN and U Genova
- INFN and U Milano
- INFN and U Napoli
- INFN and U Padova
- INFN and U Pavia
- INFN, SNS and U Pisa
- INFN, Roma and U “La Sapienza”
- INFN and U Torino
- INFN and U 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

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

March 2, 2001

C. Campagnari - UCSB
The BaBar Detector

- e\(^-\) (9 Gev)
- e\(^+\) (3.1 Gev)
- Solenoid (1.5 T)
- DIRC quartz bars
- ElectroMagnetic Calorimeter CsI(Tl) crystals
- Iron Flux Return instrumented with RPCs
- Silicon Vertex Tracker (silicon modules)
- Drift CHamber
- Silicon Vertex Tracker (silicon modules)
Silicon Vertex Tracker (SVT)

- Five layer double-sided Si
- Very low mass
- Stand-alone tracking device for $P_T < 120$ MeV/c
- Rad hard
- Semi-log readout of PH, some $dE/dX$ capabilities also
SVT hit reconstruction efficiency:
(μ+μ- events)

97%
(excluding 9 defective ROS after the installation over the total 208: no failure on Layer 1)

SVT hit Resolution:

Layer 1 - Z View

Layer 1 - φ View
Drift Chamber (DCH)

- **40 Layers**
  - (10 super-layers)
- **1.5 T field**
- **Low-mass**
  - gas 80% He-20% $\text{C}_4\text{H}_{10}$
  - Inner(outer) cylinder:
  - 0.28 (1.5) % $X_0$
**DCH performance:**

**Design:** 140 μm

\[
\frac{\sigma(p_t)}{p_t} = 0.13\% \cdot p_t (\text{GeV}/c) + 0.45\%
\]

**DCH+SVT**

\[
H_V = 1900\quad \quad H_V = 1960
\]

\[
\sigma = 7.5\% \quad \text{(design 7%)}
\]
Detector of Internally Reflected Cherenkov Light (DIRC):

\[ \cos \Theta_c = \frac{1}{n \beta} \]

\( \Theta_c \) resolution:

March 2, 2001  
C. Campagnari - UCSB
DIRC performance highlights

\[ D^0 \rightarrow K^-\pi^+ \]

Invariant mass combinations

---

March 2, 2001

C. Campagnari - UCSB 25
Electromagnetic Calorimeter (EMC)

6580 CsI(Tl) crystals (~18 $X_0$)

E.M. shower:
- Energy and angular resolution
  Range: [20MeV, 9GeV]

\[
\sigma_E \approx \frac{2.3\%}{\sqrt[4]{E\text{(GeV)}}} \oplus 1.8\%
\]

\[
\sigma_\theta = \left( \frac{3.9}{\sqrt{E\text{(GeV)}}} \right) \pm 0.04 \text{ mrad}
\]
Neutral hadrons reconstruction

\( \pi^0 \) - mass = 135.1 MeV
\( \pi^0 \) - width = 6.9 MeV

\( \sigma_m = 10 \text{ MeV}/c^2 \)
Electron id

![Graph showing the ratio of measured energy to expected deposited energy for electron identification.]

- **E/P**

![Graph showing the electron identification efficiency and pion misidentification probability as a function of momentum.]

- **Electron Identification Efficiency**
- **Pion Misidentification Probability**

---

March 2, 2001

C. Campagnari - UCSB
Instrumented Flux Return (IFR)

Large solid angle coverage for muon id ($P > 1$ GeV/c) and to detect neutral hadrons ($K^0_L$)

- Experienced degradation in efficiency throughout the run
- Some fixes in the works
Muon efficiency and pion contamination

For $17^\circ < \phi < 155^\circ$
**Sin2β Analysis Flow**

- **Reconstruct CP final-state**
  - $J/\Psi K_S(\pi^+\pi^-)$, $J/\Psi K_S(\pi^0\pi^0)$, $\Psi(2s)K_S(\pi^+\pi^-)$, $J/\Psi K_L$

- **Measure $\Delta z$ between $J/\Psi$ and tracks from other $B$**
  - Need to understand resolution function

- **Look for flavor tag among other tracks**
  - Algorithm developed on MC, tested on data
  - Mistag probability ($w$) is crucial parameter

- **Extract $\sin2\beta$ from fit to $B^0$ and $\bar{B}^0$ decay time distributions**
The B-flavor sample

- Large sample of fully reco'd decays
- Used to measure flavor tagging performance and vertexing resolution parameters
- Also, extract a measurement of the mixing parameter from these events
- Plot of $M_{ES} = \sqrt{E_{\text{beam}}^2 - P^*^2}$
The $B_{flav}$ sample (cont.)

$D(\ast)^{-}\pi^{+}$, $D(\ast)^{-}\rho^{+}$, $D(\ast)^{-}a_{1}^{+}$

$J/\psi K^{*0} \ (K^{*0} \rightarrow K^{+}\pi^{-})$

$\sim 6700$ events
Reconstructed CP final states

• **Golden modes: low backgrounds (CP=-1)**
  - $J/\Psi K_s(\pi^+\pi^-)$ 259 events, 98% purity
  - $J/\Psi K_s(\pi^0\pi^0)$ 50 events, 84% purity
  - $\Psi(2s)K_s(\pi^+\pi^-)$ 54 events, 97% purity

• **Additional mode, high background (CP=+1)**
  - $J/\Psi K_L$ 432 events, 40% purity

• **Two more modes $J/\Psi K^*(K_s\pi^0)$ and $\chi_c K_s$** not quite ready for prime time, but will come soon
\[ B^0 \rightarrow J/\psi K_S \]
\[ K_S \rightarrow \pi^+\pi^- \]

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

\[ B^0 \rightarrow \psi(2S) K_S \]
\[ K_S \rightarrow \pi^+\pi^- \]

**BaBar golden modes**
A word about $J/\Psi K_L$

- Reconstruction:
  - $K_L$ reconstructed as shower in IFR or EMC
  - Energy not measured, only direction
  - Assign $E(K_L)$ such that $M(J/\Psi K_L) = M_B$
  - Signal is peak at $\Delta E = E^*(B) - E_{\text{beam}}/2 = 0$

- High stat, but high backgrounds
  - helps reduce overall uncertainty
  - careful about CP of background!

- Opposite CP as $J/\Psi K_S$
  - eventually will provide nice cross-check
The total $J/\Psi K_L$ signal is the sum of the two
Flavor Tagging

Hierarchical algorithm - apply requirements one after the other

1. Leptons - charge of highest $P^*$ lepton

2. Kaons - total charge of identified $K$

$$\begin{align*}
\text{b} & \rightarrow l^- , \text{b} \rightarrow l^+ \\
\text{b} & \rightarrow K^- , \text{b} \rightarrow K^+
\end{align*}$$
3 Neural Network

- break NN into two categories NT1, NT2
- info from leftover leptons and Kaons, slow $\pi$ from $D^*$, charge track spectra
- two levels of NN tagging
Likelihood analysis - global fit

• Simultaneous fit to CP and $B_{\text{flav}}$ events
• Fit for $\sin 2\beta$ (CP events) and $\Delta M_d$ ($B_{\text{flav}}$ events), as well as other technical parameters
  - 9 $\Delta z$ resolution parameters
  - 4 wrong-tag probabilities ($w$) + 4 $\Delta w$ for $B^0$ vs $B^0$
  - 17 parameters related to BG

• Goals are
  - minimize reliance on MC
  - properly account for correlation in syst uncertainties
Flavor Tagging Performance from fit (info dominated by $B_{\text{flav}}$ sample)

<table>
<thead>
<tr>
<th>Tag Category</th>
<th>$\epsilon$ (%)</th>
<th>$w$ (%)</th>
<th>$Q$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lepton</td>
<td>10.9 ± 0.4</td>
<td>11.6 ± 2.0</td>
<td>6.4 ± 0.7</td>
</tr>
<tr>
<td>Kaon</td>
<td>36.5 ± 0.7</td>
<td>17.1 ± 1.3</td>
<td>15.8 ± 1.3</td>
</tr>
<tr>
<td>NT1</td>
<td>7.7 ± 0.4</td>
<td>21.2 ± 2.9</td>
<td>2.6 ± 0.5</td>
</tr>
<tr>
<td>NT2</td>
<td>13.7 ± 0.5</td>
<td>31.7 ± 2.6</td>
<td>1.8 ± 0.5</td>
</tr>
<tr>
<td>Total</td>
<td>68.9 ± 1.0</td>
<td></td>
<td>26.7 ± 1.6</td>
</tr>
</tbody>
</table>

$Q = \epsilon (1 - 2w)^2$
\[ \Delta z \text{ (or } \Delta t\text{) resolution function} \]

\[
R_{\text{reso}}(\Delta t, \Delta t_{\text{true}}, \sigma_{\Delta t} | f_{\text{tail}}, f_{\text{outlier}}, S_{\text{core}}, \delta_{\text{core}}, S_{\text{tail}}, \delta_{\text{tail}}, \sigma_{\text{outlier}}) = \\
(1 - f_{\text{tail}} - f_{\text{outlier}}) \frac{\exp - \frac{1}{2} \left( \frac{\Delta t - \delta_{\text{core}} - \Delta t_{\text{true}}}{S_{\text{core}} \sigma_{\Delta t}} \right)^2}{\sqrt{2\pi} S_{\text{core}} \sigma_{\Delta t}} \\
+ f_{\text{tail}} \frac{\exp - \frac{1}{2} \left( \frac{\Delta t - \delta_{\text{tail}} - \Delta t_{\text{true}}}{S_{\text{tail}} \sigma_{\Delta t}} \right)^2}{\sqrt{2\pi} S_{\text{tail}} \sigma_{\Delta t}} \\
+ f_{\text{outlier}} \frac{\exp - \frac{1}{2} \left( \frac{\Delta t - \delta_{\text{outlier}} - \Delta t_{\text{true}}}{\sigma_{\text{outlier}}} \right)^2}{\sqrt{2\pi} \sigma_{\text{outlier}}} \\
\]

Error from vtx fit, typically 300 fsec

Sum of 3 gaussians, Core (88%) + Tail (11%) + Outlier (1%)
Fitted parameters of resolution function

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_{\text{Core}}$</td>
<td>$1.1 \pm 0.1$</td>
</tr>
<tr>
<td>$S_{\text{Tail}}$</td>
<td>$3.8 \pm 0.9$</td>
</tr>
<tr>
<td>$f_{\text{Tail}}$ (%)</td>
<td>$11 \pm 5$</td>
</tr>
<tr>
<td>$f_{\text{Outlier}}$ (%)</td>
<td>$0.8 \pm 0.5$</td>
</tr>
<tr>
<td>$\delta_{\text{Core,Lepton}}$ (ps)</td>
<td>$0.08 \pm 0.10$</td>
</tr>
<tr>
<td>$\delta_{\text{Core,Kaon}}$ (ps)</td>
<td>$-0.21 \pm 0.05$</td>
</tr>
<tr>
<td>$\delta_{\text{Core,NT1}}$ (ps)</td>
<td>$0.01 \pm 0.10$</td>
</tr>
<tr>
<td>$\delta_{\text{Core,NT2}}$ (ps)</td>
<td>$-0.18 \pm 0.09$</td>
</tr>
<tr>
<td>$\delta_{\text{Tail}}$ (ps)</td>
<td>$-0.46 \pm 0.38$</td>
</tr>
</tbody>
</table>
Mixing result from $B_{\text{flav}}$ events

$\Delta M_d = 0.519 \pm 0.020 \pm 0.016 \text{ ps}^{-1}$ (preliminary)
Δt distributions... from ideal world to reality

Add imperfect flavor tagging
Add imperfect $\Delta t$ measurement

And throw in some background
$\Delta t$ distributions of tagged CP events

$B^0 \rightarrow J/\psi K_S^0$
$B^0 \rightarrow \psi(2S)K_S^0$

$B^0 \rightarrow J/\psi K_L^0$

$B^0$ tags

$\bar{B}^0$ tags
\[ A_{CP}(\Delta t) \]

**Golden Modes**

\[ \sin^2 \beta = 0.25 \pm 0.22 \text{ (stat)} \]

**J/\Psi K_L**

\[ \sin^2 \beta = 0.87 \pm 0.51 \text{ (stat)} \]

**Combined:**

\[ \sin^2 \beta = 0.34 \pm 0.20 \pm 0.05 \]
Some cross-checks

- Lepton
  - $J/\psi K_S^0 (\pi^+ \pi^-)$: $0.07 \pm 0.43$
  - $J/\psi K_S^0 (\pi^0 \pi^0)$: $0.40 \pm 0.29$
  - $\psi(2S) K_S^0 (\pi^+ \pi^-)$: $-0.03 \pm 0.67$
  - $J/\psi K_L^0$

- Kaon
  - $\psi(2S) K_S^0 (\pi^+ \pi^-)$: $0.87 \pm 0.51$

- NT1
  - All CP Modes
    - $B^\pm$
      - $0.34 \pm 0.20$

- NT2
  - $B^0$ (non-CP)
    - $0.02 \pm 0.05$

- All categories
  - $0.25 \pm 0.22$
  - $0.25 \pm 0.26$
  - $-0.05 \pm 0.66$
  - $0.40 \pm 0.50$
  - $0.03 \pm 0.05$
## Systematics

<table>
<thead>
<tr>
<th>Systematic</th>
<th>$J/\psi K_S^0, \psi(2S)K_S^0$</th>
<th>$J/\psi K_L^0$</th>
<th>Full sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta t$ determination</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>$J/\psi K_S^0, \psi(2S)K_S^0$ back.</td>
<td>0.02</td>
<td>—</td>
<td>0.02</td>
</tr>
<tr>
<td>$J/\psi K_L^0$ back.</td>
<td>—</td>
<td>0.09</td>
<td>0.01</td>
</tr>
<tr>
<td>$J/\psi K_L^0$ Sig. fraction</td>
<td>—</td>
<td>0.10</td>
<td>0.01</td>
</tr>
<tr>
<td>$\tau_B^0$</td>
<td>0.01</td>
<td>0.01</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>$\Delta m_{B^0}$</td>
<td>0.01</td>
<td>&lt; 0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Other</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Total</td>
<td>0.05</td>
<td>0.14</td>
<td>0.05</td>
</tr>
</tbody>
</table>
Comparison of $\sin^2 \beta$ measurements

- **BABAR**: $0.34 \pm 0.20 \pm 0.05$
- **Belle**: $0.58^{+0.32}_{-0.34} ^{+0.09}_{-0.10}$
- **CDF**: $0.79^{+0.41}_{-0.44}$
- **ALEPH**: $0.84^{+0.82}_{-1.04} \pm 0.16$
- **OPAL**: $3.20^{+1.8}_{-2.0} \pm 0.5$
- **Average**: $0.48 \pm 0.16$
Our $\sin 2\beta$ measurement and the unitarity triangle

Allowed blue region obtained without the new $\sin 2\beta$ meas.
Conclusions

• PEP-II and BaBar are operating at or above design after only one year
• BaBar is functioning well. Many new B-physics results are about to come out. Here we have reported

\[ \sin^2 \beta = 0.34 \pm 0.20 \pm 0.05 \]
\[ \Delta M_d = 0.519 \pm 0.020 \pm 0.016 \text{ ps}^{-1} \text{(prelim.)} \]

• The 2001 run is now well under way
PEP-II/BaBar luminosity projections

![Graph showing projected luminosity for years 1999 to 2005. The graph includes data for integrated luminosity in fb^-1, cumulative luminosity in 10^{33}, and peak luminosity. The table below the graph provides specific luminosity values for each year.]

<table>
<thead>
<tr>
<th>Year</th>
<th>Yearly Lumi [fb^-1]</th>
<th>Cumulative Lumi [10^{33}]</th>
<th>Peak Lumi</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2000</td>
<td>23</td>
<td>25</td>
<td>2</td>
</tr>
<tr>
<td>2001</td>
<td>40</td>
<td>65</td>
<td>5</td>
</tr>
<tr>
<td>2002</td>
<td>80</td>
<td>145</td>
<td>8</td>
</tr>
<tr>
<td>2003</td>
<td>115</td>
<td>260</td>
<td>10</td>
</tr>
<tr>
<td>2004</td>
<td>135</td>
<td>395</td>
<td>13</td>
</tr>
<tr>
<td>2005</td>
<td>225</td>
<td>620</td>
<td>24</td>
</tr>
</tbody>
</table>
Conclusions (cont.)

• High luminosity B-factories are finally a reality. We look forward to some exciting times and many new physics results.