First Year of BABAR/PEP-II

— Measuring CP Violation at an Asymmetric B Factory —

Masahiro Morii
Stanford Linear Accelerator Center
Outline

Physics — What We Measure at BABAR/PEP-II, and Why
◆ Why CP Violation?
◆ CP Violation in the B System
◆ CKM Matrix, Unitarity Triangle
◆ How to measure $\sin^2\beta$

Signal — How We Detect the CP Violation
◆ Event Signature
◆ Experimental Challenges

Experiment — How It Works
◆ PEP-II Accelerator
◆ BABAR Detector

Analysis — Where We Stand Today
◆ Signal Reconstruction
◆ Extraction of CP Violation

Summary and Outlook
**Why CP Violation**

CP violation has been known for 36 years.
- Discovered in $K_L^0 \rightarrow \pi^+ \pi^-$ decays (Christenson et al., 1964).

It occurs naturally in the Standard Model.
- Imaginary phase in the CKM matrix (Kobayashi, Maskawa, 1973).

Needed to explain the matter-dominant universe.
- What’s predicted by the SM, however, is not enough.

All the experimental evidences are in the $K^0 - \bar{K}^0$ system.
- Measurements are hard to interpret.
  - Small effects ($\epsilon = 2.3 \times 10^{-3}$) and large hadronic uncertainties.
  - Theoretically clean signal $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$ is hard to reach ($\text{BR} \sim 10^{-11}$).

Predictive power of the Standard Model has never been tested.

Is CP violation fully explained by the Standard Model?
The $B^0 - \bar{B}^0$ system is an excellent probe for CP violation studies.

- Large CP violation expected in many channels.
- “Gold-plated” channels exist with clean theoretical predictions and clean experimental signatures.

The goal: Make enough independent measurements of CP violating effects to over-constrain the Standard Model.

- NB: there is only one origin of CP violation in the SM.

Two possible outcomes:

- Everything is consistent and fully determines the CKM parameters.
  \[\rightarrow \text{CP violation is fully explained by the SM.}\]
- No single choice of CKM parameters is possible.
  \[\rightarrow \text{New physics beyond the SM.}\]
**CKM Matrix**

Wolfenstein parametrization of the CKM matrix:

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

- Approximation good to \(O(\lambda^3)\). \(\lambda = \sin\theta_C \approx 0.22\).
- CP violation due to imaginary phases in \(V_{td}\) and \(V_{ub}\).

**CP violation in mixing occurs through**

- \(V_{td} V_{ts}^* = -A^2\lambda^5(1 - \rho - i\eta)\) for \(K^0 - \bar{K}^0\).
- \(V_{td} V_{tb}^* = A\lambda^3(1 - \rho - i\eta)\) and
  
  \[
  V_{ud} V_{ub}^* = A\lambda^3(1 - \frac{\lambda^2}{2})(\rho + i\eta)
  \]

**Suppressed by \(\lambda^4\)** in the K system. No suppression in the B system.
The Unitarity Triangle

Unitarity condition $V^\dagger V = VV^\dagger = 1$ gives

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

The Unitarity Triangle:

- All sides are $O(1)$. Other triangles are squashed by $\lambda^2$ or $\lambda^4$.

The Unitarity triangle must close if the SM is correct.
Today’s Unitarity Triangle

Top corner of the UT (95% C.L.) (S. Plaszczynski, Heavy Flavours 8, 1999)

- Measurements consistent with the SM with large errors.
- Theoretical uncertainties dominate.
Today’s UT — Angles

\((\rho, \eta) \rightarrow (\sin 2\alpha, \sin 2\beta)\) plane.

- \(-0.95 < \sin 2\alpha < 0.50\) (95% C.L.)
- \(0.50 < \sin 2\beta < 0.85\) (95% C.L.)

We know very little about \(\sin 2\alpha\).

→ We need a measurement.

We know \(\sin 2\beta\) rather well.

- This is assuming the SM.

→ Direct measurement can either
  ➤ Confirm the SM.
  ➤ Indicate New Physics beyond the SM.

**CP violation in the B system allows us (BABAR and the competitors) to measure these angles.**
**CP Violation in the B system**

Consider $B^0 \rightarrow \text{CP eigenstate}\ f$.

- e.g. $f = J/\psi\ K_S$.

"Direct" and "mixed" decay amplitudes interfere with each other.

→ **Time-dependent CP asymmetry:**

$$A_{\text{CP}}(t) = \frac{\Gamma(B^0(t) \rightarrow f) - \Gamma(\overline{B}^0(t) \rightarrow f)}{\Gamma(B^0(t) \rightarrow f) + \Gamma(\overline{B}^0(t) \rightarrow f)} = C_f \cos(\Delta m \cdot t) + S_f \sin(\Delta m \cdot t)$$

- $B^0 - \overline{B}^0$ mixing frequency $\Delta m = (0.47 \pm 0.02)/\text{ps}$.

If only 1 diagram contributes to the decay,

$$C_f = 0 \quad S_f = -\text{Im}(\lambda) \quad \lambda = \frac{\langle f|\mathcal{H}|\overline{B}^0 \rangle}{\langle f|\mathcal{H}|B^0 \rangle}$$

$$A_{\text{CP}}(t) = -\text{Im}(\lambda) \sin(\Delta m \cdot t)$$
How to Measure $\sin^22\beta$

First goal: Measure $\sin^22\beta$.
- Establish CP violation outside the K system.
- Test the predictive power of the Standard Model.

Look for B decays in which:
- Single diagram dominates, and
- $\text{Im}(\lambda) = \pm \sin2\beta$, or $\text{Arg}(\langle f|\mathcal{H}|B^0}\rangle) = \mp\beta$.

Three types of decays:
- **Color-suppressed** modes:
  \[ b \rightarrow c\bar{c}s \]

- **Cabibbo-suppressed** modes:
  \[ b \rightarrow c\bar{c}d \]

- **Penguin-dominated** modes:
  \[ b \rightarrow s\bar{s}s \text{ or } b \rightarrow d\bar{d}s \]
**b → c̅c̅s Modes**

Example: \( B^0 \rightarrow J/\psi \, K_S \)

\[
\lambda = (-1) \left( \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*} \right) \left( \frac{V_{cs}^* V_{cb}}{V_{cs} V_{cb}^*} \right) \left( \frac{V_{cd}^* V_{cs}}{V_{cd} V_{cs}^*} \right) = A_{CP}(t) = \sin 2\beta \sin(\Delta m \cdot t)
\]

Is this single-diagram decay?

- **Good approximation:** the dominant penguin diagram has the same phase as the tree diagram.

**Gold-plated mode:** theoretically clean.
$b \rightarrow c\bar{c}d$ Modes

Example: $B^0 \rightarrow D^+D^-$

$$\lambda = \left( \frac{V_{t\bar{b}}}{V_{tb}} \right) \left( \frac{V_{c\bar{d}}}{V_{cd}} \right) \left( \frac{V_{d\bar{c}}}{V_{cb}} \right)$$

$$\rightarrow A_{CP}(t) = -\sin 2\beta \sin(\Delta m \cdot t)$$

The tree diagram is Cabibbo suppressed.

- Penguins with different phases contribute significantly.

Theoretically less clean (tin-plated?)
**b → s\bar{s}s and d\bar{d}s Modes**

Example: \( B^0 \rightarrow \phi K_S \), or \( \phi K^* \)

\[
\lambda = (-1) \left( \frac{V^*_{tb} V_{td}}{V_{tb} V^*_{td}} \right) \left( \frac{V^*_{cs} V_{cb}}{V_{cs} V^*_{cb}} \right) \left( \frac{V^*_{cd} V_{cs}}{V_{cd} V^*_{cs}} \right)
\]

\[
A_{\text{CP}}(t) = \sin 2\beta \sin(\Delta m \cdot t)
\]

**How about the cleanliness?**

- \( B^0 \rightarrow \phi K_S \), or \( \phi K^* \) are **pure penguin** → OK.
- \( B^0 \rightarrow d\bar{d}s \) modes: the tree is both color- and Cabibbo-suppressed → Penguin probably dominates. **Limitation**: small branching ratios.
Event Signature: $B^0 \rightarrow J/\psi K_S$

Three steps to measure $A_{CP}(t)$:

- Reconstruct one $B^0$ (or anti-$B^0$) from $J/\psi$ and $K_S$.
- Measure time from $\Delta z = \beta \gamma \Delta t$.
- Determine the flavor of the $B^0$ by *tagging* the other $B^0$.

\[
A_{CP}(t) = \frac{\Gamma(B^0(t) \rightarrow f) - \Gamma(\bar{B}^0(t) \rightarrow f)}{\Gamma(B^0(t) \rightarrow f) + \Gamma(\bar{B}^0(t) \rightarrow f)} = \sin 2\beta \cdot \sin(\Delta m \cdot t)
\]
Experimental Challenges

Exclusive reconstruction of CP eigenstates.

◆ Low branching ratios.
\[ Br(B^0 \rightarrow J/\psi K^0_s) \cdot Br(J/\psi \rightarrow l^+ l^-) \sim 5 \times 10^{-5} , \]
\[ Br(B^0 \rightarrow \phi K^0_s) \cdot Br(\phi \rightarrow K^+ K^-) \sim 5 \times 10^{-6} , \]
\[ Br(B^0 \rightarrow D^{*+} D^{*-}) \cdot Br(D^{*+} \rightarrow D^0 \pi^+) \cdot Br(D^0 \rightarrow K^- \pi^+/K^- \pi^+ \pi^0) \sim 1.4 \times 10^{-5} . \]

→ High statistics, high efficiency.

◆ High multiplicity.
→ Good detector hermeticity.

◆ Combinatorial Background.
→ Good \( p_T \) resolution. (Multiple scattering)
→ Particle identification.
→ Continuum suppression. (\( \Gamma_{bb}/\Gamma_{qq} \sim 1/3 \) at \( \Upsilon_{4S} \) )
Experimental Challenges

Precise time measurement

- $B^0\bar{B}^0$ boosted along $z$ with $\beta\gamma = 0.56 \rightarrow \langle \beta\gamma c t \rangle \sim 250 \mu m$.
- Vertex resolution:
  - for $B_{CP}$: $\sigma_z \sim 50 \mu m$.
  - for $B_{Tag}$: $\sigma_z \sim 90 \mu m$ (inclusive vertex reconstruction).

$\rightarrow \sigma(\Delta z) \sim 100 \mu m$. 
Experimental Challenges

B flavor (B^0 or anti-B^0) tagging.

- 3 basic "handles":
  - primary lepton tag: \( b \rightarrow c \ l^- \ \bar{\nu}_l \)
  - secondary lepton tag: \( b \rightarrow c \ X; \ c \rightarrow X \ l^+ \ \nu_l \)
  - kaon tag: \( b \rightarrow c \ X; \ c \rightarrow s \ X; \ s \rightarrow K^- \)

- Statistical combination of all the information using
  - Likelihood methods
  - Fisher discriminant
  - Artificial neural networks

<table>
<thead>
<tr>
<th>with perfect PID</th>
<th>( \varepsilon_{\text{tag}} ) (%)</th>
<th>( (1-2\omega)^2 ) (%)</th>
<th>( \varepsilon_{\text{effective}} ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lepton</td>
<td>39.5</td>
<td>58.0</td>
<td>22.9</td>
</tr>
<tr>
<td>Kaon</td>
<td>21.3</td>
<td>60.8</td>
<td>13.0</td>
</tr>
<tr>
<td>Combined</td>
<td>60.8</td>
<td></td>
<td>35.9</td>
</tr>
</tbody>
</table>

"Effective" efficiency as if there were no mis-tags

Dilution due to mis-tags

How often you can tag
Experimental Challenges — Summary

High statistics $\rightarrow$ High luminosity
- Accelerator performance comes first.
- Detector must cope with rate and background.

High efficiency and good mass resolution
- Maximize coverage. Minimize material.

Vertex resolution
- High-resolution, wide-coverage vertex detector.

Flavor tagging
- Particle identification.

PEP-II / BaBar designed to meet these demands.
**PEP-II Storage Ring**

- **High Energy Ring (HER)**
  - 9 GeV $e^-$ beam, up to 1 A with 1658 bunches.
  - refurbished PEP-I.
- **Low Energy Ring (LER)**
  - 3.1 GeV $e^+$ beam, up to 2 A with 1658 bunches.
- SLC linac injects beams to PEP-II.
PEP-II Storage Ring

◆ LER sits on top of the HER.
◆ 9 GeV $e^-$ + 3.1 GeV $e^+ \rightarrow \beta\gamma \sim 0.56$.

Design luminosity $= 3 \times 10^{33}$ cm$^{-2}$s$^{-1}$

$\rightarrow 3 \times 10^7$ B$^0$s / year.
First collision on May 26, 1999.

PEP-II Performance

Record day luminosity: **80 pb\(^{-1}\)/day** (cf. 42 pb\(^{-1}\)/day @ Cornell)

Integrated luminosity: **3.2 fb\(^{-1}\)**

**PEP-II has made a beautiful start-up.**
Current run continues through August 2000

→ accumulate 10 fb\(^{-1}\) on-peak
Silicon Vertex Tracker (SVT)

- 5-layer double-sided Si detector. 143k readout channels.

<table>
<thead>
<tr>
<th>Layers</th>
<th>Radii (cm)</th>
<th>Readout pitch (µm)</th>
<th>Resolution (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, 2, 3</td>
<td>3.2, 4.0, 5.4</td>
<td>50 (φ) / 100 (z)</td>
<td>10 (φ) / 12 (z)</td>
</tr>
<tr>
<td>4, 5</td>
<td>12.5, 14.0</td>
<td>80–100 (φ) / 210 (z)</td>
<td>10–12 (φ) / 25 (z)</td>
</tr>
</tbody>
</table>

- Radiation-hard up to 2 Mrad.
- Target resolution $\sigma_{xy} = \sigma_z = [50/p_T \text{ (GeV/c)} \oplus 15] \mu$m.
SVT Performance

SVT Hit Resolution vs. Incident Track Angle

Layer 1 - Z View

Data - Run 7925
Monte Carlo - SP2

Layer 1 - φ View

Data - Run 7925
Monte Carlo - SP2

◆ Achieved the target resolution for high-\(p\) tracks (15 \(\mu m\) at 0°)
Radiation on the SVT is monitored by PIN diodes

- Abort the beams in case of severe radiation
- Monitor the accumulated dose vs. “budget”

→ Still comfortable headroom under the radiation budget

- May have to replace the modules in the horizontal plane in a few years
- The rest OK for 10 years
Drift Chamber (DCH)

- 7104 hexagonal cells in 40 layers = 10 superlayers x 4 layers each.
- 4 axial and 6 stereo superlayers: AUVAUVAUVA.
- **Low mass materials** to reduce multiple scattering.
  - He:iC₄H₁₀ (80:20) gas. Al field wires.
  - Be inner cylinder (0.28% X₀). Carbon fibre outer cylinder (1.5% X₀).
  - Al endplates (12 mm forward, 24 mm backward).
DCH Performance

- He-iC₄H₁₀ (80/20) for low multiple scattering
- Single hit resolution in data (●) reached design: <140 μm

Tracks with p>1GeV/c

- dE/dx resolution ~7.5% for Bhabhas (design 7%)
- K/π separation >2σ up to 700 MeV/c → DIRC covers p > 500 MeV/c

Design Goal = 140 μm
**DIRC: the PID Device**

Detector for Internally Reflected Cerenkov light.

- Measures the angle of Cerenkov light trapped inside quartz bars due to total internal reflection.
- Light emitted at the end of the bar expands in purified water.
- An array of small-diameter PMTs detects the light.
**DIRC Design**

- 144 quartz bars. 1.7 cm thick, 4.9 m long. Arranged in 12 bar-boxes.
- Stand-off-box at the backward end contains 6 m$^3$ of purified water.
- 11,000 PMTs in 12 sectors.
**DIRC Performance**

Principle proven. More work needed to achieve $\sigma = 2$ mrad.

- Background from scattered photons. Association algorithm.
**DIRC Performance**

Efficiency ~ 80%, Rejection factor ~ 5

**Graphs:**
- **Without DIRC:** $D^0 \rightarrow K^- \pi^+$
- **With DIRC:** $D^0 \rightarrow K^- \pi^+$

**Legend:**
- BABoR

**Axes:**
- K$^-$ $\pi^+$ Mass (GeV)
- Number of events/10 MeV
Electromagnetic Calorimeter (EMC)

- 6580 CsI(Tl) crystals. 5760 in the barrel, 820 in the endcap.
- Quasi-projective geometry. Photodiode readout.
- Material in front of EMC = 0.25 $X_0$ (at 90°), 0.20 $X_0$ (at 20°).
EMC Performance

- CsI(Tl) with photodiode readout
- E(Bhabha) and m(\(\pi^0\)) resolutions close to Monte Carlo

\[ \pi^0 \text{ Mass } E_{\gamma\gamma} > 500 \text{ MeV} \]

\[ \sigma = 2.2\% \]

(\(\text{MC 2.0}\%\))

\[ \sigma = 5.3\% \]

(\(\text{MC 5.0}\%\))

Electron ID (\(p > 0.5 \text{ GeV}\))

<table>
<thead>
<tr>
<th>Electrons</th>
<th>&gt;90%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pions</td>
<td>1–2%</td>
</tr>
</tbody>
</table>

\[ \tau \rightarrow 3\pi \]

\[ K_S \rightarrow 2\pi \]
**Instrumented Flux Return (IFR)**

- **Endcap**
  - 18 RPC layers
  - 60cm of iron

- **Barrel**
  - 19 RPC layers
  - 65cm of iron

- Bakelite-based Resistive Plate Chambers (RPCs).
- Identifies muons above 0.5 GeV/c from their penetration through iron.
IFR Performance

Efficiencies for muons ($e^+e^-\mu^+\mu^-$) and pions ($\tau$ and $K_S$ decays)

>75% efficiency with ~3% $\pi$ mis-id. probability.
Are We Ready to Measure $\sin^2\beta$?

PEP-II had a terrific startup!
- Collected 3.2 fb$^{-1}$ on tape → But we need more

BaBar works beautifully
- Initial problems have been solved
- Performance very promising → Still much to do (calibration!)

Physics analysis has started
- Signals are seen in key channels → Limited statistics
→ We don’t have a CP measurement just yet

What can I show you today?

Examples of what we have done to demonstrate
- How well we understand the detector
- How well the data agree with our expectation
- How realistic is our plan to measure $\sin^2\beta$ by Summer

Everything is PRELIMINARY and improving as I speak
**Inclusive J/ψ Reconstruction**

First step: Find $J/\psi \rightarrow l^+l^-$ decays.

1. Select b-like events with $R_2 < 0.5$. (Fox-Wolfram moment ratio $W_2/W_0$)
2. Combine 2 oppositely-charged tracks.
3. Form a vertex with $P(\chi^2) > 1\%$.
4. Very loose lepton ID.

Monte Carlo signal: $\sigma(m) = 11$ MeV/c$^2$.

- Large tail in the $e^+e^-$ channel due to bremsstrahlung.
$J/\psi \rightarrow l^+ l^-$ Signal

$J/\psi \rightarrow e^+ e^- (\sim 540 \text{ pb}^{-1})$

$\sigma = 16 \text{ MeV}$

Tail due to Bremsstrahlung

$J/\psi \rightarrow \mu^+ \mu^- (\sim 380 \text{ pb}^{-1})$

$\sigma = 15 \text{ MeV}$

Background due to muon ID

◆ Efficiency consistent with expectation

→ Already reasonable, but can be improved
Inclusive $K_S \rightarrow \pi^+\pi^-$ Reconstruction

Selection:
- 2 oppositely-charged tracks. → Fit a vertex.
- $P(\chi^2) > 0.01$.
- Angle $\alpha$ between $p(K_S)$ and the flight path: $\cos \alpha > 0.999$.

Double Gaussian fit:
- $m(K_S) = 498.94 \pm 0.12$ MeV/c$^2$.
- $\sigma_1 = 2.8$ MeV/c$^2$ (69%).
- $\sigma_2 = 11$ MeV/c$^2$ (31%).
$B^0 \rightarrow J/\psi K_S$ Reconstruction

Combine $J/\psi$ and $K_S$ into $B^0$.

- $J/\psi$ mass cut: $2.5 < m < 3.28$ GeV/c$^2$ for $e^+e^-$; $\pm 3\sigma$ for $\mu^+\mu^-$.  
- Looser “lepton ID” using only the EMC.  
- $K_S$ mass cut: $\pm 3\sigma$.  
- Looser $K_S$ flight direction cut: $\cos \alpha > 0.9$.

Constrained fit using $m(J/\psi)$ and $m(K_S)$ from the PDG.

Helicity angle cut:

- $\theta_h =$ angle between $K_S$ and $l^+$ momenta in the CMS of $J/\psi$. 
  - Signal distribution $\propto \sin^2 \theta_h$.  
  - Background peaks near $\cos \theta_h = \pm 1$.  
- Cut at $|\cos \theta_h| < 0.95$.  

[Diagram of $J/\psi$ decay with $K_S$ and $l^+$ momenta]
Define signal region using 2 variables:

- $\Delta E = E_B^{CMS} - E_{beam}^{CMS}$
- "Beam-constrained" $B^0$ mass: $m_B = \sqrt{(E_{beam}^{CMS})^2 - (p_B^{CMS})^2}$

Monte Carlo signal events →

- $\sigma(\Delta E) = 10$ MeV.
- $\sigma(m_B) = 2$ MeV.

→ Define $\pm 3\sigma$ signal box.

Look at the real data now!
$B^0 \rightarrow J/\psi K_S$ Signal

$\Delta E = E_B^{CMS} - E_{beam}^{CMS}$

$m_B = \sqrt{(E_{beam}^{CMS})^2 - (p_B^{CMS})^2}$

Data $\sim 620$ pb$^{-1}$

<table>
<thead>
<tr>
<th>Signal</th>
<th>12 events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background</td>
<td>$1.4 \pm 0.2$</td>
</tr>
<tr>
<td>Expected signal</td>
<td>$9.8 \pm 1.1$</td>
</tr>
</tbody>
</table>
Crosscheck: $B^+ \rightarrow J/\psi K^+$

Charged channel $B^+ \rightarrow J/\psi (\ell^+ \ell^-) K^+$.

- Similar to the gold-plated channel.
  - Kinematics.
  - $J/\psi$ reconstruction.
- Higher BR ($9.9 \times 10^{-4}$).
- Easier reconstruction.
- Self-tagging, i.e. $B^+$ flavor known by $K^+$ charge.

→ Useful for data-based studies of
  - $J/\psi$ reconstruction efficiency.
  - Tagging algorithms.
  - Vertex resolution.

Selection is identical to $J/\psi K_S$ except for the $K^+$:

- Any good (>20 DCH hits) track.
- If available, Cerenkov angle within $\pm 6$ mrad. of expected value.
$B^+ \rightarrow J/\psi K^+ \text{ Signal}$

Data $\sim 620 \text{ pb}^{-1}$

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Signal</td>
<td>41 events</td>
</tr>
<tr>
<td>Background</td>
<td>$5.0 \pm 0.6$</td>
</tr>
<tr>
<td>Expected signal</td>
<td>$39.0 \pm 3.4$</td>
</tr>
</tbody>
</table>

$\rightarrow J/\psi K$ signals under control
- Yields agree with expectations
- Resolution OK
**Vertexing in $J/\psi K^+(K^{*0})$**

Exercise vertexing using:

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

$96\pm12$ events in $\sim1$ fb$^{-1}$ data

- $S/B \sim 6$

$\Delta z = z$-distance between:

- fully-reconstructed $B$ vertex
- vertex of the rest of the event

Signal - sideband agrees with MC (histogram)

- Width comes from lifetime

→ Machinery for vertexing works

- Needs different test for performance
**D* Signal and Vertexing**

- Δm resolution improves with beam profile constraint

**BABAR**

Before refit

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

After refit

- $\sigma_1 = 280$ keV (47%)
- $\sigma_2 = 679$ keV (53%)

**BABAR**

\~220 pb$^{-1}$

| N(D$^0$) | 668 ± 33 |
| N(bkg)   | 79 ± 11  |
| $\tau(D^0)$ | 407 ± 25 ps |
| $\sigma(t)$ | 437 ± 25 ps |
$B^0 \rightarrow D^{*-} e^+ \nu$ Signal

$\sim 390 \text{ pb}^{-1}$

$\Delta m = m(D^{*-}) - m(D^0)$, MM = missing mass

$124 \pm 19$ signal events on $92 \pm 12$ bkgd

$\rightarrow$ Will be used for a mixing measurement
$\rightarrow$ Tagging efficiency and purity $\rightarrow$ CP measurement
Extraction of $\sin 2\beta$

We know how to find the signal. Efficiency and resolution ~OK

How do we measure the CP violation?

1. Measure the distance $\Delta z$
   - Vertexing working. Studies of resolution in the data continue

2. Tag the flavor of the other $B$
   - Particle ID critical. Studies underway using post-October data
   - Mixing analysis using exclusive final states (e.g. $D^*/\nu$) will measure efficiency and mis-tag probability in the data

3. Fit the $\Delta z$ distribution signed by the tag

Full MC analyses have been performed for $J/\psi K_S$ (+ a few others)

- Expected signal yield ~160 events/10 fb$^{-1}$ (Agrees with data)
- Effective tagging efficiency ~ 22%–29% depending on the technique

$\rightarrow \sigma(\sin 2\beta) \sim 0.26–0.30$ for 10 fb$^{-1}$, depending on $\sin 2\beta$
PEP-II had a terrific first year
- Record luminosity: $1.7 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$. 80 pb$^{-1}$/day
- BABAR recorded $3.2 \text{ fb}^{-1} \rightarrow 10 \text{ fb}^{-1}$ by the end of August

BABAR is working great
- Performance approaching the design goals

Analyses are progressing rapidly
- Signals seen in key channels. Efficiency & resolution OK
- Vertexing resolution OK. More tests will follow
- Tagging being studied using real data, e.g. $B^0 \rightarrow D^* \nu$
  \[ \rightarrow \text{All ingredients for the CP measurement getting ready} \]

More data is coming!!!
- With 10 fb$^{-1}$: **Expect $\sim 160 \ J/\psi \ K_S \ events \ \rightarrow \ \sigma(\sin 2\beta) \leq 0.3$**