First Year of BABAR/PEP-II
— Measuring CP Violation at an Asymmetric B Factory —

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**CP Violation in $B^0$ Decays**

CP violation has been known for 36 years

- Occurs *naturally* in the Standard Model ← the CKM matrix
- Limited experimental constraints from $K_L$ decays

→ Is CP violation fully explained by the Standard Model?

CP violation in $B^0$ decays comes to the rescue

- Interference between direct and mixed decays produces time-dependent CP asymmetry

\[
A_{CP}(t) = \frac{\Gamma(B^0 \to f_{CP}) - \Gamma(\bar{B}^0 \to f_{CP})}{\Gamma(B^0 \to f_{CP}) + \Gamma(\bar{B}^0 \to f_{CP})} = A_{CP} \sin(\Delta m \cdot t)
\]

Asymmetry $A_{CP}$ is related to the CKM angles $\alpha, \beta, \gamma$

- E.g. $A_{CP} = \sin 2\beta$ for $B^0 \to J/\psi K_S$ (gold-plated decay)

→ Powerful probe to verify/disprove the SM prediction
**How We Measure CP Violation**

1. **Reconstruct a CP decay** (e.g. $B^0 \rightarrow J/\psi K_S$)
   - Low BR $(5 \times 10^{-5})$ → luminosity & detector efficiency
2. **Tag the flavor of the other $B^0$**
   - Leptons and kaons → particle identification
3. **Measure $\Delta z$ → $t = \Delta z/\beta\gamma c$**
   - Asymmetric collider ($\beta\gamma = 0.56$)
   - Vertex resolution → silicon vertex tracker

The formula for $A_{CP}(t)$ is:

$$A_{CP}(t) = \frac{\Gamma(B^0 \rightarrow f_{CP}) - \Gamma(\bar{B}^0 \rightarrow f_{CP})}{\Gamma(B^0 \rightarrow f_{CP}) + \Gamma(\bar{B}^0 \rightarrow f_{CP})} = A_{CP} \sin(\Delta m \cdot t)$$
**PEP-II Storage Ring**

\[ 9 \text{ GeV } e^- + 3.1 \text{ GeV } e^+ \rightarrow \beta \gamma \sim 0.56 \]

First collision May 26, 1999

<table>
<thead>
<tr>
<th></th>
<th>Design</th>
<th>Achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminosity (cm(^{-2}\text{s}^{-1}))</td>
<td>(3 \times 10^{33})</td>
<td>(1.7 \times 10^{33})</td>
</tr>
<tr>
<td>No. of bunches</td>
<td>1658</td>
<td>829</td>
</tr>
<tr>
<td>LER current (mA)</td>
<td>2140</td>
<td>960</td>
</tr>
<tr>
<td>HER current (mA)</td>
<td>610</td>
<td>750</td>
</tr>
</tbody>
</table>

>1/2 design luminosity achieved
PEP-II Integrated Luminosity

3.8 fb\(^{-1}\) delivered
3.2 fb\(^{-1}\) recorded

Current run continues through August 2000

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

- 5 layer double-sided Si detector
- Hit resolution in data (●) reached design: ~15 µm at 0°
- Radiation hard up to 2 Mrad
Drift Chamber (DCH)

- Tracks with $p > 1\text{GeV/c}$

- Design Goal = 140 $\mu$m

- He-iC$_4$H$_{10}$ (80/20) for low multiple scattering

- Single hit resolution in data (●) reached design: <140 $\mu$m

- $dE/dx$ resolution ~7.5% for Bhabhas (design 7%)

- $K/\pi$ separation >2$\sigma$ up to 700 MeV/c → DIRC covers $p > 500$ MeV/c
**DIRC: the PID Device**

- Cerenkov light in quartz \( \rightarrow \) transmitted by internal reflection \( \rightarrow \) detected by PMTs
- 3 mrad resolution achieved (target 2 mrad)
- \( K/\pi \) separation at 4 GeV/c is 6.5 mrad

- **K** efficiency \( \sim 80\% \) for \( D^0 \to K^+\pi^- \) inside the acceptance
- Background rejection factor \( \sim 5 \) (NB: background contains kaons)

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First Year of BaBar/PEP-II 
Masahiro Morii 
SLAC
Electromagnetic Calorimeter (EMC)

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

$\pi^0$ Mass $E_{\gamma\gamma} > 500$ MeV

$\sigma = 5.3\%$ (MC 5.0%)

Electron ID ($p > 0.5$ GeV)

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

$\tau \rightarrow 3\pi$

$K_S \rightarrow 2\pi$
Instrumented Flux Return (IFR)

- Bakelite-based RPCs sandwiched between iron plates
- Muons above $p = 0.5$ GeV/c identified
- Neutral hadrons ($K_L$) detected

Muon ID ($p > 0.5$ GeV)

<table>
<thead>
<tr>
<th>Muons</th>
<th>&gt;75%</th>
</tr>
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<tbody>
<tr>
<td>Pions</td>
<td>~3%</td>
</tr>
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</table>

$e^+e^- \rightarrow e^+e^-\mu^+\mu^-$

$\tau \rightarrow 3\pi$

$K_S \rightarrow 2\pi$
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
\( J/\psi \rightarrow l^+l^- \) 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

\[ \text{Efficiency consistent with expectation} \]

→ Already reasonable, but can be improved
\[ K_S \rightarrow \pi^+\pi^- \text{ Signal} \]

- Mass resolution OK

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<tbody>
<tr>
<td>Mass</td>
<td>498.94 ± 0.12 MeV</td>
</tr>
<tr>
<td>(\sigma_{\text{narrow}})</td>
<td>2.8 MeV (69%)</td>
</tr>
<tr>
<td>(\sigma_{\text{wide}})</td>
<td>11 MeV (31%)</td>
</tr>
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</table>
$B^0 \rightarrow J/\psi \ K_S$ Signal

$\Delta E = E^\text{CMS}_B - E^\text{CMS}_\text{beam}$

$m_B = \sqrt{(E^\text{CMS}_\text{beam})^2 - (p^\text{CMS}_B)^2}$

Data ~620 pb$^{-1}$

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

Data ~620 pb$^{-1}$

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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>

→ $J/\psi K$ signals under control
- Yields agree with expectations
- Resolution OK
- Bkg will improve (calibration, PID)
**D* Signal and Vertexing**

- Δm resolution improves with beam profile constraint

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

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

- Simple exponential $\otimes$ gaussian fit
- Resolution as expected
- Lifetime consistent with PDG

~220 pb$^{-1}$
$B^0 \rightarrow D^{*-} e^+ \nu$ Signal

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

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

$\sim 120$ signal events

$\rightarrow$ Will be used for a mixing measurement
$\rightarrow$ Tagging efficiency and purity $\rightarrow$ CP measurement
Summary and Outlook

PEP-II had a terrific first year
◆ Record luminosity: $1.7 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$. $80 \text{ pb}^{-1}/\text{day}$
◆ 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. $B^0 \rightarrow D^*/\nu$

→ All ingredients for the CP measurement getting ready

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