Measurements of $B^0$ and $B^{\pm}$
Lifetimes and $B^0$-$\bar{B}^0$ Mixing with fully-reconstructed $B$ decays

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Parallel Session PA-07
Overview

(1) $B^0$ or $B^\pm$ fully reconstructed
   ✔ hadronic
   ✔ semileptonic
   Remainder is other $B$

(2) Reconstruction of decay vertices
   ✔ Decay time difference $\Delta t \propto \Delta z$
   ✔ Resolution function $\Rightarrow \sin 2\beta$ analysis
   ✔ Lifetime measurements

(3) $B^0/\bar{B}^0$ flavor tagging
   ✔ Leptons, Kaons
   ✔ Neural Networks

(4) Time dependent mixing rate
   ✔ Mistag rate $\psi \Rightarrow \sin 2\beta$ analysis
   ✔ $\Delta m_d$ measurement

For details: SLAC-PUB-8529 and SLAC-PUB-8530
$\bar{B}^0 \rightarrow D^{*+} \pi^-$

$\Rightarrow D^0 \pi^+$

$\Rightarrow K^- \pi^+$

$B^0 \rightarrow K^- X$

Kaon Tag
The BABAR Detector at PEP-II B-Factory

**Data Set**

- 8.9 fb\(^{-1}\) on-resonance
- 0.9 fb\(^{-1}\) off-resonance

- **e\(^{-}\) (9 GeV)**
- **e\(^{+}\) (3 GeV)**
- **Silicon Vertex Tracker (SVT)**
- **Superconducting Coil (1.5T)**
- **Drift Chamber (DCH)**
- **CsI Calorimeter (EMC)**
- **Instrumented Flux Return (IFR)**
- **Cherenkov Detector (DIRC)**
Hadronic decays

- $B^0 \rightarrow D^(*) \pi^+$, $D^(*) \rho^+$, $D^(*) a_1^+$, $J/\Psi K^*$
- $B^- \rightarrow D^{(*)0} \pi^-$, $J/\Psi K^-$, $\Psi(2S) K^-$
- Kinematic variables for signal and background estimates
  \[ \Delta E = E^*_B - \sqrt{s}/2 \]
  \[ m_{ES} = \sqrt{(s/4 - p^*_B)^2} \]

For details:
G. Vuagnin, G. Raven’s talks
PA-07e, Saturday

Background from $m_{ES}$ sideband
- ARGUS shape
- Combinatorial
  - ~4% fake B same charge, ~3% fake B opp charge
  - ~5% ccbar, ~1% uds

2577±59  
Purity ~ 86%

2636±56  
Purity ~ 89%
Semileptonic decays

- \( B^0 \rightarrow D^*-l^+\nu_l \)

- Identify electrons and muons using calorimeter and Instrumented Flux Return

- \( D^* \) and lepton tend to be back-to-back, \( p^*(\text{lepton}) > 1.2 \text{ GeV} \)

- Require kinematic consistency with missing neutrino

\[ |\cos \theta(B,D^*l)_{\text{CM}}| < 1 \]

(\text{equivalent to missing-mass cut})

Background from control samples

- Combinatorial \( \Rightarrow D^* - D \) sideband
- Wrong-lepton:
  - fake leptons \( \Rightarrow \) tracks + lepton mis-id
  - uncorrelated leptons \( \Rightarrow \) “lepton-flipping”
  - cascade leptons \( \Rightarrow < 1\% \) (Simulation)
  - \( c\bar{c} \Rightarrow \) off-resonance data
- \( B^\pm \) background (\( B^- \rightarrow D^{*-} X \ l^+ \nu_l \) (\( D^{**} \))
  - \( \Delta t \) distributions from hadronic \( B^+ \)
  - fraction from LEP data and MC simulation:
  \[ f(B^+) = (7.1 \pm 5.0)\% \]
Decay time difference

✔ Boost approximation

\[ \Delta t = \frac{(z_{REC} - z_{TAG})}{c <\beta\gamma>} \]

✔ Resolution function

- largely dominated by TAG side
- most relevant parameters extracted from likelihood fit to data
- uses event-by-event error
- described by 3 Gaussians:
  - \( f_{\text{core}} \sim 75\%, \sigma_{\text{core}} \sim 0.6 \text{ ps} \)
  - \( f_{\text{tail}} \sim 24\%, \sigma_{\text{tail}} \sim 2 \text{ ps} \)
  - \( f_{\text{outliers}} \sim 1\%, \sigma_{\text{outliers}} \sim 8 \text{ ps} \)
- slightly biased (~0.2 ps) due to secondary decays

Monte Carlo

Background (Monte Carlo)

Hadronic Data
Lifetime measurements

- Simultaneous unbinned maximum likelihood fit to $\Delta t$ distributions of hadronic $B^0$ and $B^\pm$ data with common resolution function
- Empirical $\Delta t$ background description from $m_{ES}$ sidebands, different parameters for $B^0$ and $B^-$
- Use full $m_{ES}$ distribution to define signal probability
- Results based on 7.4 fb$^{-1}$

$\tau_{B^0} = 1.51 \pm 0.05$ (stat) $\pm 0.03$ (syst) ps
$\tau_{B^+} = 1.60 \pm 0.05$ (stat) $\pm 0.04$ (syst) ps
$\tau_{B^+}/\tau_{B^0} = 1.065 \pm 0.044$ (stat) $\pm 0.021$ (syst)

- Systematics dominated by
  - Monte Carlo statistics
  - Understanding of outliers
  - $z$ scale
B flavor tagging

✔ Determine the flavor of the B by the charge of decay products

✔ **Effective tagging efficiency**

\[ Q = \varepsilon D^2, \ D = 1-2\mu \]

\[ \frac{1}{\sigma^2_{stat}} \sim N_{Brec} Q \]

**Fraction of tagged events**

**Dilution**

**Wrong tag fraction**

✔ 4 mutually exclusive tagging categories

<table>
<thead>
<tr>
<th>Category</th>
<th>Priority</th>
<th>Definition</th>
<th>$\varepsilon$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lepton</strong></td>
<td>+</td>
<td>Charge of fastest lepton with $p^* &gt; 1.1$ GeV/c. Higher priority to electrons over muons</td>
<td>12.1 ± 0.5%</td>
</tr>
<tr>
<td><strong>Kaon</strong></td>
<td>-</td>
<td>Total charge of identified kaons</td>
<td>36.2 ± 0.9%</td>
</tr>
<tr>
<td><strong>NT1</strong></td>
<td>-</td>
<td>Neural Network, $</td>
<td>x_{NT}</td>
</tr>
<tr>
<td><strong>NT2</strong></td>
<td>-</td>
<td>Neural Network, $0.2 &lt;</td>
<td>x_{NT}</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>74.6 ± 0.5%</td>
</tr>
</tbody>
</table>

✔ **Neural network** exploits information carried by non-identified leptons and kaons, soft leptons (from charm semileptonic decays), soft pions from D* decays, and more generally, by the momentum spectrum of charged particles (Jet Charge) from B decays
Mixing results: hadronic decays

Simultaneous likelihood fit to each tagging category, mixed and unmixed events with common resolution function

$$\frac{1}{4} \Gamma e^{-\Delta t} \left[ 1 \pm (1-2w)\cos \Delta m_d \Delta t \right] \otimes R(\Delta t;a)$$

Empirical $\Delta t$ background description from $m_{ES}$ distribution (same shape, different resolution function). Two components:
- zero lifetime
- non-zero lifetime, no mixing

Use full $m_{ES}$ distribution to define signal probability

Result:

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

Systematics dominated by
- Monte Carlo statistics
- Resolution function

PRELIMINARY
Mixing results: semileptonic decays

Similar procedure as for hadronic decays with two main differences

Fit separately background control samples. Three components:
- zero lifetime
- non-zero lifetime, no mixing
- non-zero lifetime, mixing

Fit data in signal region with background fractions, $\Delta t$ resolutions and dilutions from background control samples

Result:

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

Systematics dominated by
- Monte Carlo statistics
- Resolution function
- $B^\pm$ background uncertainty

28% C.L.
Mixing results

$\Delta m_d = 0.512 \pm 0.017 \text{ (stat)} \pm 0.022 \text{ (syst)} \, \text{ps}^{-1}$

$\alpha(\Delta t) = (N_{\text{unmix}} - N_{\text{mix}})/(N_{\text{unmix}} + N_{\text{mix}})$
Outlook and Prospects

✔ PRELIMINARY measurements of $B^0$, $B^-$ lifetimes (~4%) and $B^0\bar{B}^0$ Mixing (~3%) with first 8.9 fb$^{-1}$ of BaBar data

$\tau_{B^0} = 1.51 \pm 0.05$ (stat) $\pm 0.03$ (syst) ps
$\tau_{B^+} = 1.60 \pm 0.05$ (stat) $\pm 0.04$ (syst) ps
$\tau_{B^+}/\tau_{B^0} = 1.065 \pm 0.044$ (stat) $\pm 0.021$ (syst)

$\Delta m_d = 0.512 \pm 0.017$ (stat) $\pm 0.022$ (syst) ps$^{-1}$

✔ Mixing provides resolution function and mistag rates for sin2$\beta$ analysis (D. Hitlin’s talk at plenary session)

<table>
<thead>
<tr>
<th>Particle</th>
<th>$Q$ $\pm$</th>
<th>(stat) $\pm$</th>
<th>(syst)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lepton</td>
<td>0.096</td>
<td>0.017 (stat)</td>
<td>0.013</td>
</tr>
<tr>
<td>Kaon</td>
<td>0.197</td>
<td>0.013 (stat)</td>
<td>0.011</td>
</tr>
<tr>
<td>NT1</td>
<td>0.167</td>
<td>0.022 (stat)</td>
<td>0.020</td>
</tr>
<tr>
<td>NT2</td>
<td>0.331</td>
<td>0.021 (stat)</td>
<td>0.021</td>
</tr>
</tbody>
</table>

$Q$ $\sim$ 28%

✔ Further systematic studies underway; more Monte Carlo statistics

✔ More data being delivered by PEP-II (>20 fb$^{-1}$ for end october)