B lifetime measurements with exclusively reconstructed B decays

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Introduction

- $\Upsilon(4S) \rightarrow B^0\overline{B}^0, B^+B^-$
- Reconstruct one $B^0$ or $B^\pm$ exclusively, in hadronic or semileptonic decays.
- Remainder of particles are from the other $B$.
- Reconstruct two $B$ vertices.
- $\Delta z = c[(\beta_z \gamma t)_{\text{reco}} - (\beta_z \gamma t)_{\text{other}}] \approx c (\beta_z \gamma) B \Delta t$
- $(\beta_z \gamma)_B \approx p_z(\Upsilon) / M(\Upsilon)$
- $P(\Delta t) \sim \exp(-|\Delta t| / \tau_B)$

\[\Upsilon(4S) \rightarrow B^0\overline{B}^0, PEP-II\]

$\beta_z \gamma \sim 0.56$

$\Delta z \sim 250 \mu m$
BABAR detector

- Tracking: 5-layer Silicon Vertex Tracker (SVT) 40-layer Drift Chamber (DCH)
  - \[(\delta p_T/p_T)^2 = (0.0015p_T)^2 + (0.005)^2, \quad p_T \text{ in GeV/c}\]
  - SVT single hit resolution ~ 10\(\mu\)m
  - Impact parameter resolution
    50-100 \(\mu\)m for \(p_T > 0.6\) GeV/c

- \(\pi^0\) reco: CsI(Tl)
  Electromagnetic calorimeter (EMC)
**BABAR detector and data set**

- **Particle ID:**
  - SVT, DCH (dE/dx)
  - EMC (electrons)
  - Instrumented Flux Return (muons),
  - Detection of Internally Reflecting Cherenkov light

- **Data set: Jan.- June 2000**
  - 7.4 fb⁻¹ near $\Upsilon(4S)$ peak
    - ~8.4 M $B^0\bar{B}^0$ and $B^+B^-$ pairs
  - 0.9 fb⁻¹ 40 MeV below peak
Hadronic decay modes

- Fully reconstructed modes:
  - $B^0 \rightarrow D^{(*)-}\pi^+, D^{(*)-}\rho^+, D^{(*)-}a_1^+, J/\psi K^0 + \text{C.C.}$
  - $B^- \rightarrow D^{(*)0}\pi^-, J/\psi K^-, \psi(2S)K^- + \text{C.C.}$

- Observables:
  \[ \Delta E = E^*_B - \sqrt{s}/2, \quad m_{ES} = \sqrt{\left(\frac{\sqrt{s}}{2}\right)^2 - p_B^{*2}} \]
Vertex reconstruction

• Fully reconstructed B:
  » The whole decay tree is fitted by a kinematic and geometric fitter.
  » \( z \) Resolution: 45-65 \( \mu \)m depending on mode

• The opposite B:
  » Use tracks not from fully reconstructed B
  » Form \( V^0 \)'s to reduce bias from long lived particles.
  » Fit tracks, \( V^0 \)'s and the “pseudo-track” (the flight path of the B estimated from reco B, \( \Upsilon(4S) \) momentum and beamspot constraint), removing tracks with large \( \chi^2 \) contribution iteratively.
  » \( z \) Resolution: \(~115 \) \( \mu \)m, with \(~25 \) \( \mu \)m bias.
**Δz resolution**

- Dominated by the opposite vertex.
- Similar for different modes – will use the same resolution function for all modes.
- Both residual and pull distributions can be well described by $G+G$ or $G\otimes(1+E)$; the latter is used.

**Quality cuts**

- $|\Delta z| < 3000 \mu m$
- $\sigma(\Delta z) < 400 \mu m$
- $n_{\text{opptracks}} \geq 2$
**Lifetime fits**

- Unbinned maximum likelihood fit.

\[ \text{PDF} = [p_{\text{sig}} \cdot S(\Delta z, \sigma; \tau_{B0}, \tau_{B+}, \theta_{\text{resol}}) + (1 - p_{\text{sig}} - f_{\text{out}}) \cdot B(\Delta z; \theta_{\text{bkg}}) + f_{\text{out}} \cdot O(\Delta z)] \]

- \( p_{\text{sig}} \): probability of being signal based on \( m_{ES} \) spectrum and ARGUS background shape.
- \( S() \): signal modeling, two-sided exponential convoluted with \( \Delta z \) resolution function, same resolution is used for \( B^0 \) and \( B^\pm \).
- \( B() \): background modeling, gaussian plus two independent exponential towards either side.
- \( O() \): outliers, a broad gaussian (fixed mean (0) and width (2500\( \mu \)m)) to account for a handful of outliers.
- \( f_{\text{out}} \): outlier fraction, a few per mil in Data.
Results

• $\tau_0 = 1.506 \pm 0.052\text{(stat)} \pm 0.029\text{(syst)} \text{ ps}$
• $\tau_{\pm} = 1.602 \pm 0.049\text{(stat)} \pm 0.035\text{(syst)} \text{ ps}$
• $\tau_{\pm}/\tau_0 = 1.065 \pm 0.044 \pm 0.021$

PDG2000
$\tau_0 = 1.548 \pm 0.032$
$\tau_{\pm} = 1.653 \pm 0.028$
$\tau_{\pm}/\tau_0 = 1.062 \pm 0.029$

single best
$\tau_0 = 1.474 \pm 0.039 \pm 0.051 \text{ (CDF)}$
$\tau_{\pm} = 1.643 \pm 0.037 \pm 0.025 \text{ (OPAL)}$
$\tau_{\pm}/\tau_0 = 1.110 \pm 0.065 \pm 0.033 \text{ (CDF)}$
## Systematic uncertainties

<table>
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<tr>
<th>Systematic effect</th>
<th>$\delta \tau_0$ (fs)</th>
<th>$\delta \tau_{\pm}$ (fs)</th>
<th>$\delta (\tau_{\pm}/\tau_0)$</th>
<th>comment</th>
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<td>0.001</td>
<td>Some included in stat error (free param)</td>
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<td></td>
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<td>15</td>
<td>16</td>
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<tr>
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<td>-</td>
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<td>Signal probability</td>
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<td>0.005</td>
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<td>5</td>
<td>17</td>
<td>0.011</td>
<td>Compare distributions of bkg events under signal and sideband</td>
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<td>Total in quadrature</td>
<td>29</td>
<td>35</td>
<td>0.021</td>
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</tbody>
</table>
Semileptonic modes

- Lifetime measurement from semileptonic modes is in progress
  - $\bar{B}^0 \rightarrow D^{*+} l^- \nu$
  - $D^+ \rightarrow D^0 \pi^+$
  - $D^0 \rightarrow K^- \pi^+, K^- \pi^+ \pi^0, K^- \pi^+ \pi^+ \pi^-$

- ~10K (combinatoric subtracted) events reconstructed (8.8 fb$^{-1}$)

- Larger background level (~15%)
  - Combinatoric, continuum, uncorrelated lepton, fake lepton, $B^- \rightarrow D^{*+} X l^- \nu$

- Use control samples from data to estimate background fractions and $\Delta t$ distributions used in fit.

- Expect statistical error: ~2%
Conclusions

• Hadronic modes
  » $\tau_0 = 1.506 \pm 0.052^{\text{(stat)}} \pm 0.029^{\text{(syst)}} \text{ ps}$
  » $\tau_\pm = 1.602 \pm 0.049^{\text{(stat)}} \pm 0.035^{\text{(syst)}} \text{ ps}$
  » $\tau_\pm/\tau_0 = 1.065 \pm 0.044^{\text{(stat)}} \pm 0.021^{\text{(syst)}}$

Consistent with other measurements
Already very competitive with other measurements
Expect $> 20 \text{ fb}^{-1}$ this year, more studies needed to reduce systematic errors

• Semileptonic modes
  » background under control
  » expected statistical error for $8.8 \text{ fb}^{-1} \approx 2\%$
  » systematic uncertainties still being studied