B\(^+\) and B\(^0\) Meson Lifetimes
Status and Prospects

- Quick review of Decay Length method
- Motivation for looking at Impact Parameter method
- Impact Parameter fit results
- Combining the two analyses
- Estimate of errors once VXD-only tracks are used
- Plans for summer conferences
**B⁺/B⁰ Analysis Outline**

- **Reconstruct decay point** of B mesons using ZVTOP & calculate decay length from IP
- **Divide sample into “B⁰” and “B⁺” samples**
- **Use** $M_{PT}$, $Q_{vtx}$, and $A_{FB}(\cos\theta)$ **to improve purity of samples**
- **Determine lifetime by fitting MC to the Data**
  - **decay length distributions**
- **Calculate Systematics**
Summary

- SLD Measurement still the most precise for lifetimes & ratio
- $\tau_{B^+}/\tau_{B^0} \sim 1\sigma$ deviation from naïve spectator model prediction
- World sees 2.8$\sigma$ dev.
- Need greater precision to discriminate between theoretical predictions

$\tau_{B^+}/\tau_{B^0}$

- $1.065 \pm 0.023$
- WA (12/99): $1.065 \pm 0.023$
Crosschecks

Very important - results are most precise for now, but will be “checked” in ~ 1 yr by BaBar & few years down the road by CDF/D0

• $\tau$ as a function of
  – decay length cuts (min,max)
  – $\cos \theta, \phi$ regions

• error magnitude checks (work in progress)
  – errors scale from previous results
  – Data errors agree with MC predictions
  – examining MC pulls, etc.
## Lifetime Systematics (97-98 Decay Length Analysis)

<table>
<thead>
<tr>
<th>Physics Systematics</th>
<th>$\Delta \tau_{B^+}$ (ps)</th>
<th>$\Delta \tau_{B^0}$ (ps)</th>
<th>$\Delta \tau_{B^+/\tau_{B^+}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>B frag.</td>
<td>$0.714 \pm 0.008$</td>
<td>$0.025$</td>
<td>$0.030$</td>
</tr>
<tr>
<td>$X_E$ shape</td>
<td>$0.011$</td>
<td>$0.009$</td>
<td>$&lt;0.003$</td>
</tr>
<tr>
<td>B(B→DD)</td>
<td>$0.18 \pm 0.05$</td>
<td>$0.015$</td>
<td>$0.014$</td>
</tr>
<tr>
<td>b baryon fraction</td>
<td>$0.072 \pm 0.040$</td>
<td>$0.004$</td>
<td>$0.017$</td>
</tr>
<tr>
<td>$B_s^0$ lifetime</td>
<td>$1.49 \pm 0.06$</td>
<td>$&lt;0.003$</td>
<td>$0.014$</td>
</tr>
<tr>
<td>TOTAL (all systs, including tracking &amp; detector)</td>
<td>$0.033$</td>
<td>$0.044$</td>
<td>$0.026$</td>
</tr>
</tbody>
</table>

- b fragmentation systematics dominant for individual lifetimes
Can we use a variable that is less sensitive to $X_E$?

**Analysis Outline:**
- As before, find ZVTOP vertices
- As before, divide sample into charged & neutral
- As before, enhance $B^\pm$ purity using $A_{FB}$, $M_{PT}$, etc.
- Use the **Average** of the 3D Impact Parameters of the Vertex Tracks with respect to the IP

$$L \sim \tau \cdot E \leftrightarrow \text{Large } L = \frac{\text{Long } \tau}{\text{or}} \text{ Hard } X_E$$

$$\delta \sim L \cdot \theta \sim (\tau \cdot E) \cdot \theta \sim (\tau \cdot E) \cdot (1/E) \rightarrow \delta \text{ independent of } X_E$$
How does the Impact Parameter distribution look?

Reasonably good agreement!
Instead, look @ **Average** of the 3D impact parameters for the tracks in the vertex
(nice thing: 1 entry/evt; less dependence on B-decay model)

<table>
<thead>
<tr>
<th>Decay Length</th>
<th>$\tau_{B^+}$ (± stat) psec</th>
<th>$\tau_{B^0}$ (± stat) psec</th>
<th>$\tau_{B^+}/\tau_{B^0}$ (± stat)</th>
<th>Total $\chi^2$ (76 dof)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ave. of 3D impact Parameters</td>
<td>1.660 ± 0.024</td>
<td>1.577 ± 0.024</td>
<td>1.052 ± 0.027</td>
<td>80</td>
</tr>
<tr>
<td>Degree of correlation with dkl analysis</td>
<td>1.638 ± 0.025</td>
<td>1.547 ± 0.027</td>
<td>1.057 ± 0.032</td>
<td>79</td>
</tr>
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$\rho = \left\langle \left( \tau_{dkl} - \bar{\tau}_{dkl} \right) \left( \tau_{b3} - \bar{\tau}_{b3} \right) \right\rangle / \sigma_{dkl} \sigma_{b3}$
Degree of correlation between two analyses

From Decay Length Method:

From Ave. 3D impact Method:

Correlation Coefficient:

$$\rho = \frac{\langle (x - \bar{x})(y - \bar{y}) \rangle}{\sqrt{\langle (x - \bar{x})^2 \rangle \langle (y - \bar{y})^2 \rangle}}$$

March 16, 2000
SLD B-lifetime/B-mixing Review

Ken Baird
Univ. of Massachusetts
**Lifetime Systematics** *(97-98 Ave. b3 Analysis)*

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<tr>
<th>Physics Systematics (selected subset)</th>
<th>$\Delta \tau_{B^+}$ (ps)</th>
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<td>$X_E$ shape</td>
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<td>0.009 ± 0.005</td>
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<td>0.033 ± 0.008</td>
<td>0.044 ± 0.015</td>
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*(all systs, including trkng & detector)*

*But, others now much more important!*  
*e.g. B decay multi:* 0.019 0.013 0.019  
*(used to be negligible)*

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Want to combine methods, but since data is the same, we must worry about correlations:

*Unfortunately, we’re not yet sure how!*

**Trial #1: treat it like an intersecting track problem**

**Prob. Dist.:**

\[ p(x, y) = \left( \frac{1}{2\pi\sigma_1\sigma_2\sqrt{1-\rho^2}} \right) \times \]

\[
\exp \left\{ -\frac{1}{2} \left( \frac{1}{1-\rho^2} \right) \left[ \frac{y - y_1(x)}{\sigma_1} \right]^2 + \left[ \frac{y - y_2(x)}{\sigma_2} \right]^2 - \frac{2\rho \left\{ y - y_1(x) \right\} \left\{ y - y_2(x) \right\}}{\sigma_1\sigma_2} \right\} \]

**Bottom Line: Didn’t Work!**
Trial 2: Assume can write lifetimes in following form:

\[
\tau_{d\text{kl}}(x) = f\tau_1(x) + (1-f)\tau_2(x) \\
\tau_{b3}(x) = f\tau_1(x) + (1-f)\tau_3(x)
\]

*By design, \(\tau_1, \tau_2, \tau_3\) are uncorrelated*

\[
\sigma_{\tau_{d\text{kl}}}(x) = f\sigma_{\tau_1}(x) \oplus (1-f)\sigma_{\tau_2}(x) \\
\sigma_{\tau_{b3}}(x) = f\sigma_{\tau_1}(x) \oplus (1-f)\sigma_{\tau_3}(x)
\]

Still working on this, but not converging
How much better might the $\tau$ results get...

• ...if we use Dan Dong’s $X_E$ ($\sim 0.709 \pm 0.006$)?
  − For LP99, we used $\sigma_{XE} = \pm 0.008$
    − $\tau_{B^+} = 1.623 \pm 0.020 \pm 0.034$ psec
    − $\tau_{B^0} = 1.565 \pm 0.024 \pm 0.044$ psec
    − $R = 1.030 \pm 0.028 \pm 0.026$ stays the same

• ...if we combine the two analyses?
  − $\rho \sim 0.7$, so maybe stat error reduces $\sigma \rightarrow \sqrt{\rho \sigma} \rightarrow 0.85\sigma$
    • $\sigma_{STAT}(B^+) \rightarrow 0.017$
    • $\sigma_{STAT}(B^0) \rightarrow 0.020$
    (but systs prob. won’t reduce as much as above)

• ...if we use VXD-only tracks?
  − From T. Wright: tag purity goes from $\sim 0.79\%$ to $\sim 0.82\%$
    • so A.P. = $|2P-1|$ goes from 0.58 to 0.64 (10\% improvement)
    • $\sigma_{STAT}(B^+) \rightarrow 0.017 \rightarrow 0.015$; $\sigma_{STAT}(B^0) \rightarrow 0.020 \rightarrow 0.018$
How much better might the $\tau$ results get...

- …if we use Dan Dong’s $X_E$ ($\sim .709 \pm .006$)?
  - For LP99, we used $\sigma_{XE} = \pm .008$
    - $\tau_{B+} = 1.613 \pm .023 \pm 0.034$ psec
    - $\tau_{B0} = 1.565 \pm .024 \pm 0.044$ psec
    - $R = 1.030 \pm .028 \pm .026$ stays the same
- …if we combine the two analyses?
  - $\rho \sim 0.7$, so *maybe* stat error reduces $\sigma \rightarrow \sqrt{\rho \sigma} \rightarrow 0.85\sigma$
    - $\sigma_{STAT}(B^+) \rightarrow .020$ *(but systs prob. won’t reduce as much as above)*
    - $\sigma_{STAT}(B^0) \rightarrow .020$
- …if we use VXD-only tracks?
  - From T. Wright: tag purity goes from $\sim .79\%$ to $\sim .82\%$
    - so A.P. = $|2P-1|$ goes from 0.58 to .64 (10% improvement)
    - $\sigma_{STAT}(B^+ & B^0) \rightarrow .020 \rightarrow .018$
So........

\[ \tau_{B^+} = 1.613 \pm 0.018 \pm 0.030 \text{ psec} \]
\[ \tau_{B^0} = 1.565 \pm 0.018 \pm 0.042 \text{ psec} \]
\[ R = 1.030 \pm 0.021 \pm 0.026 \]

or........

\[ \sigma_\tau / \tau(B^+) = 2.5\% \rightarrow 2.1\% \]
\[ \sigma_\tau / \tau(B^0) = 3.2\% \rightarrow 2.9\% \]
\[ \sigma_R / R = 3.7\% \rightarrow 3.2\% \]
Plans & Goals

- For Valencia conference (Hyperons, Charm and Beauty Hadrons; late June), we want to release “almost final” results for 1996-98 data
  - combination of dkl and ave. b3 analyses
  - using VXD-only tracks
  - using best estimate of $X_E$
  - completed physics note

  Results must freeze by mid-June

- Publication plans: draft 0 will be B-lifetime PRL using 1993-95 data
Backup stuff for next few pages
Summary

WA (12/99): 1.656 ± 0.025 ps

\[ \tau_B^+ \]

**World average**

**SLD**

**ALEPH D^{(*)+}**

(ALEPH exclusive)

CDF J/\psi K

CDF D^{(*)+}

DELPHI D^{(*)+}

DELPHI topology

L3 Topology

OPAL topology

OPAL D^{(*)+}

SLD vert. + 1

SLD topology

B Lifetime Working Group

March 16, 2000

Ken Baird

SLD B-lifetime/B-mixing Review

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Summary

\( \tau_{B^0} \)

SLD (12/99): \( 1.562 \pm 0.029 \) ps

World average

\( \tau (B^0) \) (ps)

1.565 \pm 0.021 \pm 0.021 \) ps (LP99)

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For LP99, we used 1997-98 R16 Data and MC. However, the tracking corrections were based upon R15. Now, using R16 tracking corrections.

- ~ 30 K charged ($|Q_{vtx}|=1,2,3$)
- ~ 20 K neutral ($|Q_{vtx}|=0$)
- For analysis, require
  - $|Q_{vtx}| \leq 3$
  - $L > 1$ mm
  - $R < 2.2$ cm
  - $M_{Pt} > 2$ GeV/c$^2$
  - $M_{Pt} < 5.2$ GeV/c$^2$
We combine info from I.S. Tagging (Pol + Q_{jet}) and Q_purity(M_{pt}) to assign vertices to either a "B^0" or "B^+" distribution. Each entry is weighted by the P_{B0} or P_{B+}.

"B^0" sample purity =

"B^+" sample purity =
Binned Decay Length Fits (1997-98)

LP99 plots
(Before Mean Shifts)

Latest:

- $\tau_{B^+} = 1.660 \pm 0.024$ ps
- $\tau_{B^0} = 1.577 \pm 0.024$ ps
- $\frac{\tau_{B^+}}{\tau_{B^0}} = 1.052^{+0.028}_{-0.026}$

(Before Mean Shifts)
What do we actually report to conferences?

- \( \tau_{B^+} = 1.658 \pm 0.023 \pm 0.033 \) ps
- \( \tau_{B^0} = 1.580 \pm 0.025 \pm 0.044 \) ps

We shifted central values of lifetimes to account for differences between MC centroid values for different systs. & what we want to use as a central value (assume linear extrapolation OK):

- \( \bar{X}_E \) (MC) = .698 → .714 : \( \tau_{B^+} \rightarrow 1.607 \) ps
- \( \bar{\tau}_{B^0} \) (MC) = 1.55 ps → 1.49 ps : \( \tau_{B^+} \rightarrow 1.607 \) ps
- \( f_{b\text{-baryon}} \) (MC) = 7.2% → 10.2% : \( \tau_{B^+} \rightarrow 1.613 \) ps

- \( \tau_{B^+} = 1.613 \pm 0.023 \pm 0.033 \) ps
- \( \tau_{B^0} = 1.565 \pm 0.025 \pm 0.044 \) ps

1997-98 results (LP99, before shifts)

Won't need to do these two in future

1997-98 results (LP99, after shifts)
Recall from last collab. mtg:

Lifetime dependence on $X_E$

Decay Length Analysis

Ave 3D Impact Parameter Analysis

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Physics systematics for both analyses

<table>
<thead>
<tr>
<th>Decay Length</th>
<th>Average 3D imp. par.</th>
</tr>
</thead>
<tbody>
<tr>
<td>b fragmentation</td>
<td>0.02456 0.02934 0.00363</td>
</tr>
<tr>
<td>bowler shape</td>
<td>0.01044 0.00863 0.00098</td>
</tr>
<tr>
<td>BR(B--&gt;DX)</td>
<td>0.00505 0.00846 0.00712</td>
</tr>
<tr>
<td>BR(B--&gt;DDX)</td>
<td>0.01445 0.01365 0.01602</td>
</tr>
<tr>
<td>B decay multi.</td>
<td>0.00072 0.00267 0.00126</td>
</tr>
<tr>
<td>B_s fraction</td>
<td>0.00298 0.00116 0.00266</td>
</tr>
<tr>
<td>b_baryon frax.</td>
<td>0.00410 0.01656 0.00826</td>
</tr>
<tr>
<td>b_s lifetime</td>
<td>0.00003 0.01356 0.00891</td>
</tr>
<tr>
<td>B baryon life</td>
<td>0.00036 0.00528 0.00324</td>
</tr>
<tr>
<td>D decay multi.</td>
<td>0.00327 0.00536 0.00559</td>
</tr>
<tr>
<td>D decay K0 yield</td>
<td>0.00153 0.00832 0.00452</td>
</tr>
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