A Measurement of the Time Dependence of $B_d - \bar{B}_d$ Mixing with Kaon Tagging

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• Introduction
• Likelihood Parameterization
• Results
B_d Mixing with a Kaon tag

Steps to Making a Mixing Measurement:

- Use SLD Combined Initial State Tag
- Final state uses the charge of the kaon.

B_d Right Sign Fraction: $(82 \pm 5)\%$ (Argus)

Would result in a large systematic: Fit to this instead!
- Reconstruct B decay vertex and determine proper time
Topological $B$ Event Selection

- Compute $M_{raw}$ mass of tracks in secondary vtx (assign $m_{\pi}$)
- Exploit additional mass information from kinematics:

$$M = \sqrt{M_{raw}^2 + P_T^2 + P_T^2}$$

Results with cut at $m_{Pt} = 2$ Gev:
- 98.3% Purity
- 55.3% Efficient
Analysis Event Selection

- Select neutral vertices

- High $B_d$ Fraction:
  - $B_d = 0.607$
  - $B_u = 0.146$
  - $B_s = 0.170$
  - Baryons = 0.067

![Graph](image-url)
Polarized Forward-Backward Asymmetry (SLD only)
Left- (right-) polarized e⁻ tags forward hemisphere quark as b (b)

Opposite Side Tags
Jet Charge \( \Sigma_{\text{tracks}} Q_i |p_i \cdot T|^\kappa \)
Secondary vtx charge \( Q_{vtx} \)
Kaon charge \( b \rightarrow c \rightarrow s \) (i.e. \( K^- \))
Lepton charge \( b \rightarrow l^- \)
Dipole charge \( \delta q = (Q_D - Q_B) \) \( \delta q > 0 \) for b quark

Tags combined in most analyses + event-by-event mistag probabilities
Mistag rates \( w \sim 0.22 - 0.25 \)
SLD Kaon Identification

Using the Cherenkov Ring Imaging Detector

π-K separation
0.5 < p < 4 GeV/c: liquid radiator
2.5 < p < 30 GeV/c: gas radiator

π→K MisID:
- rate calibrated with K^0 → π^+ π^- Data
- rate varies from 2.5-10% as a function of momentum

Excellent Kaon Identification:
81% Purity
40% Efficiency
Monte Carlo Fit Information

Decay Length Resolution
\[ \sigma_c = 79.3 \text{ \(\mu\)m} \]
\[ \sigma_t = 421.4 \text{ \(\mu\)m} \]
*Double Gaussian fit, 67% core*

Relative Boost Resolution
\[ \sigma_c = 6.77\% \]
\[ \sigma_t = 20.9\% \]
*Double Gaussian fit, 55% core*

B Kaon Right Sign Fractions:
\[ B_d = 0.797 \]
\[ B_u = 0.776 \]
\[ B_s = 0.497 \]
Baryons = 0.614

2-D Unbinned Likelihood Fit in Monte Carlo:
\[ \Delta m_d = 0.487 \pm 0.016 \text{ ps}^{-1} \quad B_d \text{ RSF} = 0.802 \pm 0.010 \]
*The SLD Monte Carlo is generated with \(\Delta m_d = 0.484 \text{ ps}^{-1}\).*
Likelihood Fit Results - Data

$\Delta m_d = 0.545 \pm 0.034 \text{ ps}^{-1}$

$B_d \text{ RSF} = 0.814 \pm 0.023$

number of vertices: 7844

(1996-1998 Data)

The world average for $\Delta m_d$ as of Moriond 2001 is $0.484 \pm 0.010 \text{ ps}^{-1}$. 
<table>
<thead>
<tr>
<th>Source</th>
<th>$\sigma(\Delta m_d) \text{ (ps}^{-1})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_u$ Lifetime (1.64 ± 0.027)</td>
<td>±0.001</td>
</tr>
<tr>
<td>$B_d$ Lifetime (1.55 ± 0.024)</td>
<td>±0.002</td>
</tr>
<tr>
<td>Baryon Lifetime (1.22 ± 0.052)</td>
<td>±0.001</td>
</tr>
<tr>
<td>$B_u$ Fraction (.146 ± 0.010)</td>
<td>±0.005</td>
</tr>
<tr>
<td>$B_d$ Fraction (.607 ± 0.010)</td>
<td>±0.003</td>
</tr>
<tr>
<td>$B_s$ Fraction (.170 ± 0.012)</td>
<td>±0.002</td>
</tr>
<tr>
<td>Baryon Fraction (.067 ± 0.017)</td>
<td>±0.002</td>
</tr>
<tr>
<td>Udsc Fraction (.012 ± .006)</td>
<td>±0.001</td>
</tr>
<tr>
<td>$B_u$ RSF (.776 ± 0.05)</td>
<td>±0.012</td>
</tr>
<tr>
<td>Baryon RSF (.614 ± 0.05)</td>
<td>±0.007</td>
</tr>
<tr>
<td>$\Delta m_s$ (10 + 10 ps$^{-1}$)</td>
<td>±0.001</td>
</tr>
<tr>
<td>Boost Resolution (± 20%)</td>
<td>±0.018</td>
</tr>
<tr>
<td>Decay Length Resolution (± 20%)</td>
<td>±0.001</td>
</tr>
<tr>
<td>Tracking Resolution (Correction On/Off)</td>
<td>±0.005</td>
</tr>
<tr>
<td>Track Efficiency (Correction On/Off)</td>
<td>±0.004</td>
</tr>
<tr>
<td>$\pi^+$ Misidentification (Calibration Statistics)</td>
<td>±0.003</td>
</tr>
<tr>
<td>Initial State Tagging (± 0.02)</td>
<td>±0.005</td>
</tr>
</tbody>
</table>
Summary

- This is the only $B_d$ mixing measurement using a kaon for the final state tag.

- Previous SLD all-analysis average:
  \[ \Delta m_d = 0.526 \pm 0.043 \text{ (stat)} \pm 0.031 \text{ (syst)} \text{ ps}^{-1} \] (1993-95 Data)

- Preliminary Kaon tag result:
  \[ \Delta m_d = 0.545 \pm 0.034 \text{ (stat)} \pm 0.025 \text{ (syst)} \text{ ps}^{-1} \] (1996-98 Data)
Background Parameterization

The **udsc background** is parameterized using a *gaussian with power law tails*:

\[
\begin{align*}
    l_1 & \leq x \leq l_2 : f(x) = p_1 \left(-0.5 \left(\frac{x-p_2}{p_3}\right)^2\right) \\
    x & \leq l_1 : f(x) = p_1 \frac{p_5 \ln \left(\frac{p_3 p_5}{p_4}\right)}{p_5 \ln \left(\frac{p_2 + p_3 p_5}{p_4} - p_3 p_4 - x\right)} e^{0.5 p_4^2} \\
    x & \geq l_2 : f(x) = p_1 \frac{p_7 \ln \left(\frac{p_3 p_7}{p_6}\right)}{p_5 \ln \left(\frac{p_3 p_7}{p_6} - p_3 p_6 - p_2 + x\right)} e^{0.5 p_6^2}
\end{align*}
\]

*Where the \( p_i \) represent the fit parameters, and\*

\[
    l_1 = p_2 - p_3 p_4, \quad l_2 = p_2 + p_6 p
\]
Unbinned Log-Likelihood Fit to $\Delta m_d$

For a single event, the probability to mix is:

\[
f_{Bd} P_{mix,Bd} + f_{Bs} P_{mix,Bs} + f_{Bu} P_{mix,Bu} + f_{Baryon} P_{mix,Baryons} + f_{udsc} P_{mix,udsc}
\]

Where the individual terms are as follows:

\[
P_{mix,Bd} = \frac{\Gamma_{Bd}}{2} e^{-\Gamma_{Bd} t} (1 - (1 - 2R_{Bd} - 2i + 4R_{Bd} i)\cos(\Delta m_d t))
\]

\[
P_{mix,Bu} = \Gamma_{Bu} e^{-\Gamma_{Bu} t} (R_{Bu} + i - 2R_{Bu} i)
\]

- $B_s$ is analogous to $B_d$, and the Baryons to $B_u$. The parameterization of the detector resolution and efficiencies and the background term are described on the next slides.

- $f_{(b)}$ is the fraction of that $B$ type (parameterized in MC); $i$ is the initial state right sign probability; $t$ is the proper time and is parameterized in the fit by an integral over the resolution and efficiency of the detector.

- $R_{(b)}$ is the kaon right sign fraction for that $B$ type, parameterized from MC.