$B_s$ Mixing and $B$ Hadron Lifetimes at CDF

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- Proton-antiproton Synchrotron
- Run II:
  \[ \sqrt{s} = 1.96 \text{ TeV} \]
  – Both experiments have now \( > 2.5 \text{ fb}^{-1} \) on tape.
  – Aim for 6-8 \( \text{ fb}^{-1} \) by 2009
CDF-Detector

- Tracking: Silicon Detector + Drift Chamber (COT)
- PID: Muon chambers
  - ToF
  - dEdx (COT)
  - Calorimeter
- Huge background: soft QCD 1000x larger → trigger to find secondary vertex
  - 2-track trigger (TTT):
    - Pt(trk)>2GeV/c
    - IP(trk)>100 µm
- Di-Muon Trigger
Mixing Introduction

- flavoured neutral mesons can turn into their antiparticle via box diagrams
  - measuring oscillation frequency
  - measure $|V_{ts}|$

- $\Delta m$ ratio $\rightarrow$ measure one side of unitarity triangle (many theoretical uncertainties cancel in ratio)

- new physics can influence oscillation frequency $\rightarrow$ test of Standard Model

\[
\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s}}{m_{B_d}} \xi^2 \frac{|V_{ts}|^2}{|V_{td}|^2}
\]
Mixing: Overview

- For mixing you need 3 ingredients:
  - Get flavour at decay
  - and at production

- good proper time resolution for decay vertex reconstruction → mixed or not mixed after a specific time
Decay Flavour and Channels

\[ B_s \rightarrow D_s \, \pi \]
\[ B_s \rightarrow D_s \, 3\pi \]
\[ B_s \rightarrow D_s \, l^+ X \quad D_s \rightarrow \phi \, \pi \]
\[ D_s \rightarrow K^* K \]
\[ D_s \rightarrow 3\pi \]

- Flavour specific modes, to get b flavour at decay
Production Flavour: Flavour Tagging

- Estimate flavour at **production** from the rest of the event
  - Opposite side - NN combination: $\varepsilon D^2 = 1.8\%$
    - Lepton identification: $b \to Xl^-$, but cascade: $b \to c \to Xl^+$
    - Jet-Charge: inclusive charge of fragmentation
    - Kaon identification: $b \to c \to XK^-$
  - Same side: $\to \varepsilon D^2 = 3.5\%$ (hadronic) $- \varepsilon D^2 = 4.8\%$ (S.L.)
    - Kaon identification: the other s quark not in the $B_s$ will create a $K$
Proper Time Resolution @ CDF

- Good proper time resolution requires excellent tracking as close as possible to the interaction point
  - Excellent tracking with large drift chamber (COT)
  - followed by the silicon detector with closest layer at about 1 cm from beam for good vertex resolution
Mixing Results

\[ P_S(t, \xi, \sigma_t) \propto \frac{1 + \xi A D \cos(\Delta m t) \frac{1}{1 + |\xi|}}{\frac{1}{\tau}} e^{-t/\tau} \]

- fit only amplitude and fix frequency
- scan through frequencies
- Fourier Analysis which should have maximum at true oscillation frequency
- unbinned maximum likelihood fit >5\(\sigma\) significance:
  - \(\Delta m_s = 17.77 \pm 0.10 \pm 0.07\) ps\(^{-1}\)
  - \(|V_{td}/V_{ts}| = 0.2060 \pm 0.0007\) (exp)
  - \(|V_{td}/V_{ts}| = 0.2060 \pm 0.0007\) (theo.)
\[ \Lambda_b \rightarrow J/\psi \Lambda \]

- Fully reconstructed decay channels
- Control channels with very similar topology:
  - \( B^0 \rightarrow J/\psi K_s \)
  - \( B^0 \rightarrow J/\psi K^* \)
  - \( B^+ \rightarrow J/\psi K^+ \)
  - \( B^0_s \rightarrow J/\psi \phi \)
- di-muon vertex used for lifetime measurement
- \( J/\psi \rightarrow \mu\mu \rightarrow \) di-muon Trigger:
  - \( 2.7 \text{GeV/c}^2 < M(\mu\mu) < 4 \text{GeV/c}^2 \)
  - \( Q(\mu_1) \times Q(\mu_2) = -1 \)
  - \( p_t(\mu) > 1.5 \text{GeV/c} \)
Control Channels

\[ N(J/\psi K^*) \sim 3600 \]

\[
cr(B^0) = 457.1 \pm 8.8\,(\text{stat}) \pm 3.2\,(\text{syst})\,\mu m
\]

\[
\tau(B^0) = 1.524 \pm 0.030\,(\text{stat}) \pm 0.011\,(\text{syst})\,ps
\]

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Control Channels

B^+ lifetime measurements

| Experiment        | B^+ lifetime [ps] |
|-------------------|-------------------|
| SLD (ABE 97J)     | 1.660±0.060±0.050 ps |
| L3 (ACCIARRI 98S)| 1.660±0.060±0.030 ps |
| CDF (ABE 98Q)     | 1.637±0.058 (±0.045-0.043) ps |
| OPAL (ABBIENDI 99I)| 1.643±0.037±0.025 ps |
| ALEP (BARATE 00R)| 1.648±0.049±0.035 ps |
| BABR (AUBERT 0F1)| 1.673±0.032±0.023 ps |
| CDF (ACOSTA 02C)| 1.636±0.058±0.025 ps |
| DLPH (ABDALL. 04E)| 1.624±0.014±0.018 ps |
| BELL (ABE 05B)   | 1.635±0.011±0.011 ps |
| CDF Run II Prelim.| 1.630±0.016±0.011 ps |
| **World Average**| **1.638±0.011 ps** |

B^0 lifetime measurements

| Experiment        | B^0 lifetime [ps] |
|-------------------|-------------------|
| BABR (AUBERT 01F)| 1.546±0.032±0.022 ps |
| BABR (AUBERT 02H)| 1.529±0.012±0.029 ps |
| CDF (ACOSTA 03C)| 1.533±0.034±0.038 ps |
| BABEL (AUBERT 03H)| 1.497±0.073±0.032 ps |
| D0 (ABAZOV 05W)  | 1.531±0.021±0.031 ps |
| CDF (ACOSTA 05)  | 1.540±0.050±0.020 ps |
| BELL (ABE 05B)   | 1.534±0.008±0.010 ps |
| BABR (AUBERT 06G)| 1.530±0.043±0.023 ps |
| CDF Run II Prelim.| 1.504±0.013 (+0.018-0.013) ps |
| **World Average**| **1.530±0.009 ps** |
Control Channels

- All control channels provide excellent lifetime measurements
- Consistent with world average
Λ_{b} Results

\[ N(J/\psi \Lambda) = 532 \]

\[
c\tau(\Lambda_{b}^0) = 473.8 \pm 23.1 \text{(stat)} \pm 3.5 \text{(syst)} \mu m
\]

\[
\tau(\Lambda_{b}^0) = 1.580 \pm 0.077 \text{(stat)} \pm 0.012 \text{(syst)} ps
\]
Λ_b Comparison

- 3σ deviation from WA
- Lifetime ratio:

\[ \frac{\tau(\Lambda_b^0)}{\tau(B^0)} = 1.018 \pm 0.062 \text{(stat)} \pm 0.007 \text{(syst)} \]

- Theory prediction:

\[ \tau(\Lambda_b^0)/\tau(B^0) = 0.88 \pm 0.05 \]
Summary

• First observation of $B_s^0 - \bar{B}_s^0$ Oscillations $>5\sigma$
  – very precise $\Delta m_s$ measurement
  – Published: Phys. Rev. Lett., 97, 242003 (2006)

• Most precise single $\Lambda_b$ lifetime measurement
  – other $b$-hadron lifetimes agree with world average
  – $\Lambda_b$ lifetime is $3\sigma$ above world average and at the upper side of theoretical prediction
  – $\Lambda_b \rightarrow \Lambda_c \pi$ lifetime measurement in progress

• More info @:
  http://www-cdf.fnal.gov/physics/new/bottom/bottom.html