Recent Heavy Flavor Results

Lifetimes, FCNC, & Rare Decays at the Tevatron

Sneha Malde
University of Oxford & University of Pittsburgh
on behalf CDF and D0

General purpose detectors recording $p\bar{p}$ collisions at $\sqrt{s} = 1.96$TeV
Hadron Lifetimes

Spectator model: all B hadrons have the same lifetime

Difference from light quark interactions

Expected Hierarchy:

\[ \tau(B_u) > \tau(B_d) \sim \tau(B_s) > \tau(\Lambda_b) \gg \tau(B_c) \]

Ratio Predictions (HQE):

\[ \tau(B^+) = 1.063 \pm 0.027 \tau(B_d) \]

\[ \tau(\Lambda_b) = 0.88 \pm 0.05 \tau(B_d) \]

Lifetimes important for understanding the interactions of quarks inside hadrons

HQE is used to calculate \( \Gamma_{12} \) and semileptonic asymmetry
Lifetimes in decays with $J/\Psi$

4 Channels: $B^+ \rightarrow J/\Psi K^+$
$B^0 \rightarrow J/\Psi K^*$
$B^0 \rightarrow J/\Psi K_S$
$\Lambda_b \rightarrow J/\Psi \Lambda$

Uses 4.3 fb$^{-1}$ of data

Aims to solve the $\Lambda_b$ ‘puzzle’

Yield in the control modes gives opportunity for the most precise $B^+$ and $B^0$ lifetimes
Analysis Strategy

Data from the di-muon trigger -Selection based on rectangular cuts only

<table>
<thead>
<tr>
<th>Decay</th>
<th>Lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^+ \to J/\psi K^+$</td>
<td>$45000 \pm 230$</td>
</tr>
<tr>
<td>$B^0 \to J/\psi K^*$</td>
<td>$16860 \pm 140$</td>
</tr>
<tr>
<td>$B^0 \to J/\psi K_S$</td>
<td>$12070 \pm 120$</td>
</tr>
<tr>
<td>$\Lambda_b \to J/\psi \Lambda$</td>
<td>$1710+50$</td>
</tr>
</tbody>
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Yields in 4.3 fb$^{-1}$

Use the $J/\psi$ vertex to determine the Decay Vertex for all modes

Makes detector resolution similar for all channels

Use the $J/\psi$ sample for further study

Lifetime extracted from an un-binned likelihood fit, simultaneously in mass, decay time and decay time error
Controlling systematic uncertainties

Large yields in $B^+$ & $B^0$

Systematically limited using simple modeling of detector resolution.

Background is mainly prompt.

Carefully model the mass sideband data ➔ extract the scale factors that determine the detector resolution.

Overall systematic reduction for analysis:

$0.016$ ps ➔ $0.008$ ps ($B^0$)

Systematic error now limited by detector alignment.
B⁺ Fit Projections
Results shown against PDG and other measurements

Most precise measurement of the $B^+/B^0$ ratio

In agreement with theoretical prediction:

$\tau(B^+) = (1.063 \pm 0.027) \tau(B_d) \text{ (theory)}$

$\tau(B^+) = (1.088 \pm 0.009 \pm 0.004) \tau(B_d) \text{ (exp)}$
Λ_b Fit Projections

CDF Run II Preliminary 4.3 fb^{-1}

- Data
- Data fit
- Sideband region

CDF Run II Preliminary 4.3 fb^{-1}

- Data
- Signal
- Bkg
- Signal+Bkg

CDF Run II Preliminary 4.3 fb^{-1}

- Data
- Signal
- Bkg
- Signal+Bkg

Events/2 MeV/c^2

Events/0.50 cm

Events/1 cm

Mass (J/ψ Λ)[GeV/c^2]

cτ (J/ψ Λ) [cm]
Most precise $\Lambda_b$ lifetime measurement

With 4.3 fb$^{-1}$ the $\Lambda_b$ lifetime remains higher in comparison to other measurements.

Measured Ratio: $\tau(\Lambda_b)/\tau(B_d) = 1.020\pm 0.030$ (stat)$\pm 0.008$ (syst)

Theory: $\tau(\Lambda_b)/\tau(B_d) = 0.88\pm 0.05$, although there are theories that favor a higher ratio 0.9-1.0
Heavier Baryons

CDF and D0 have observed the $\Xi_b$ and $\Omega_b$ baryons

CDF uses these samples to measure lifetimes
Baryon lifetimes

Low statistics (esp bkg) motivates a different approach to lifetime measurement

Data divided in bins of decay time

Mass fit in each bin determines $N(\text{sig. cand})$

Number of signal candidates in each ct bin fitted to determine lifetime.

Method tested and validated on $\Lambda_b$ and $B^0$ decay channels

\[
\tau(\Xi_b^-) = 1.56^{+0.27}_{-0.25} (\text{stat}) \pm 0.02 (\text{syst}) \text{ ps}
\]

\[
\tau(\Omega_b^-) = 1.13^{+0.53}_{-0.40} (\text{stat}) \pm 0.02 (\text{syst}) \text{ ps}
\]

First fully reconstructed measurement

First measurement
Flavor changing Neutral Currents

Forbidden at tree level

$B_d, B_s \rightarrow \mu\mu$ highly studied. In the standard model expected branching ratios:

$\text{BR}(B_s \rightarrow \mu^+\mu^-) = (3.86 \pm 0.57) \times 10^{-9} \ (|V_{ts}|^2)$
$\text{BR}(B_d \rightarrow \mu^+\mu^-) = (1.00 \pm 0.14) \times 10^{-10} \ (|V_{td}|^2)$

Beyond the reach of the detector sensitivities.

New physics scenarios Brx100

MSSM $\text{Br} \propto \tan^6(\beta)$

RPV also sensitive at low tan beta

Limits on these ratios place constraints on new physics models.

Limits can be set for $B_s$ and $B_d$ separately

Non-minimal flavor violating models can affect each mode differently.
$B(B_s^0 \rightarrow \mu\mu) = N(B_s^0 \rightarrow \mu\mu) \times k$

$$k = \frac{1}{N(B^+)} \times \frac{\varepsilon(B^+)}{\varepsilon(B_s^0)} \times f\left(\frac{b \rightarrow B^+}{b \rightarrow B_s^0}\right) \times B(B^+ \rightarrow J/\Psi K^+, J/\Psi \rightarrow \mu^+\mu^-)$$

- **Efficiency ratio from MC**
- **Fragmentation ratio between $B^+$ & $B_s$**
- **Branching fraction of normalization channel**
Background rejection

Boosted Decision Tree used to reduce background. Inputs:

• $B_s$ Isolation
• $P_T$
• $Vtx \chi^2$
• $IP/\sigma_{IP}$
• $L_{xy} / \sigma_{Lxy}$ (2D flight distance)

Very similar method used at CDF: slightly different variables and use of a neural net discriminant
Results

3 increasing bins of NN

$\text{Br}(B_d \rightarrow \mu\mu) < 7.6 \times 10^{-9}$ (95%CL)

$\text{Br}(B_s \rightarrow \mu\mu) < 4.3 \times 10^{-8}$ (95%CL)

$0.8 < v_{NN} < 0.85$

$0.85 < v_{NN} < 0.995$

$0.995 < v_{NN} < 1.0$

3 data periods

Expected upper limit (5 fb$^{-1}$)

$\text{Br}(B_s \rightarrow \mu\mu) < 5.3 \times 10^{-8}$ (95%CL)
Search for \((B_s \rightarrow \mu \mu)\) already reduced allowed parameter space of SUSY models

These analysis analyse 3.7 and 5 fb\(^{-1}\). More on tape

mSUGRA Arnowitt et al PLB 538 (2002) 121
$B \rightarrow \mu \mu \ h$

SM Br $\sim 10^{-6}$ - Are observable

Interesting observables:

• Differential BR

• Muon F-B asymmetry

Sensitive to Wilson Coefficients - Indicate whether underlying dynamics are governed by SM or NP

$$A_{FB}(q^2) = \frac{\Gamma(q^2, \cos \theta_{\mu} > 0) - \Gamma(q^2, \cos \theta_{\mu} < 0)}{\Gamma(q^2, \cos \theta_{\mu} > 0) + \Gamma(q^2, \cos \theta_{\mu} < 0)}$$
Observation of $B \rightarrow \mu\mu h$ decays

Selection optimized by neural net

$B \rightarrow J/\Psi h$ used as a control channel in measuring relative BR

\[ \text{Br}(B^0 \rightarrow \mu\mu K^*) = (1.06 \pm 0.14 \pm 0.09) \times 10^{-6} \]

\[ \text{Br}(B^+ \rightarrow \mu\mu K^+) = (0.38 \pm 0.05 \pm 0.03) \times 10^{-6} \]

\[ \text{Br}(B_s \rightarrow \mu\mu \phi) = (1.44 \pm 0.33 \pm 0.46) \times 10^{-6} \]

Competitive with world averages

First Observation

CDF Public Note 10047
New physics could also appear in the differential $\text{Br} \ vs \ q^2 = M_{\mu\mu}^2$

SM maximum

SM minimum

Uncertainty arises from SM form factors

Consistent with the SM
Asymmetry

$F_L$: $K^*$ Long Polarisation

Muon forward-backward asymmetry

J/$\Psi$ & $\Psi'$ veto

No inconsistencies with SM

Similar precision to B factory results

SM prediction

BSM scenario
Conclusions

Best Lifetimes, Best Limits, First Observations, ..... 

Tevatron continues to showcase the possibilities of flavor physics at hadron colliders

Today’s presentations shows results with less than half the expected Run 2 dataset. 

Tevatron will continue to set tough standards to beat
CDF - selection

Similar strategy to D0. Uses ANN to reduce background

Variables

• $\lambda^{3D}$ (proper decay time)
• Bs isolation
• $\Delta\alpha^{3D}$ (opening angle)
• $\lambda^{3D}/\sigma_{\lambda^{3D}}$
• $P_T(B_s)$
• $P_T(\mu)$

Looks for $B_s$ and $B_d$ separately

Non-minimal flavor violating models can affect each mode differently.