Masses, Lifetimes and Decays of B Hadrons at the Tevatron

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for the CDF and D0 collaborations

March 2003
XXXVIIth Rencontres de Moriond
QCD & Hadronic Interactions
Production

- Production $\mathcal{O}(10^5)$ larger than $\gamma_{4s}/Z^0$
  - though total inelastic X-section $10^3$ bigger $\Rightarrow$ needs adequate trigger
- All B species: $B^+, B^0, B_s, B_c, \Lambda_b, \ldots$

Topics

- QCD
  - $J/\psi$ cross-section
  - B cross-section
  - quarkonium states
- Production, masses and lifetimes: $B^+, B^0, B_s, \Lambda_b, B_c$
- Rare decays

- CP violation and mixing
  - $B_s$ mixing: $B_s^0 \rightarrow D_s \pi$, $B_s^0 \rightarrow D_s l \nu X$
  - $\sin(2\beta)$ in $B^0 \rightarrow J/\psi K_s^0$
  - weak phase of $V_{ts}$ in $B_s^0 \rightarrow J/\psi \phi$
  - CP asymmetries in $B \rightarrow h^+ h^-$
  - $\gamma$: $B_s^0 \rightarrow D_s K$
Triggers and data samples

Triggers

<table>
<thead>
<tr>
<th>D0 Di-Muon</th>
<th>CDF Di-Muon</th>
</tr>
</thead>
<tbody>
<tr>
<td>✦ $p_T^\mu &gt; 3.5 \text{ GeV}/c$, $</td>
<td>\eta^\mu</td>
</tr>
<tr>
<td>✦ $p_T^\mu &gt; 2 - 2.5 \text{ GeV}/c$, $1 &lt;</td>
<td>\eta^\mu</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>CDF Lepton + (displaced track)</th>
<th>CDF Two-track trigger</th>
</tr>
</thead>
<tbody>
<tr>
<td>✦ $\mu^\pm$: $p_T &gt; 4 \text{ GeV}/c$, $</td>
<td>\eta</td>
</tr>
<tr>
<td>✦ $e^\pm$: $p_T &gt; 4 \text{ GeV}/c$, $</td>
<td>\eta</td>
</tr>
<tr>
<td>✦ SVT: $p_T &gt; 2 \text{ GeV}/c$, $d_0 &gt; 120\mu m$</td>
<td></td>
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</tbody>
</table>

Data sample

D0: results in this talk based on 40-45 pb$^{-1}$ (Aug 2002-Jan 2003)

CDF: results in this talk based on 60-70 pb$^{-1}$ (Feb 2002-Dec 2002)
based on the decay length $L = \beta \gamma c t = \frac{p_B}{m_B} c t$, $\beta \gamma$ from Monte-Carlo

systematics: resol. function, background modeling, $\beta \gamma$ correction, alignment

CDF July 2002 (18 pb$^{-1}$) $\tau = 1.526 \pm 0.034$ (stat.) $\pm 0.035$ (syst.) ps

D0 March 2003 (40 pb$^{-1}$) $\tau = 1.561 \pm 0.024$ (stat.) $\pm 0.074$ (syst.) ps

PDG 2002 $\tau = 1.564 \pm 0.014$ ps
Di-muon: $B$ exclusive lifetime

CDF Run II Preliminary

$B^+ \to J/\psi K^+$

747±33 signal candidates
Fit prob: 71%

$\sigma \sim 15$ MeV

D0 Run II Preliminary

$B^+ \to J/\psi K^+$

$N = 378 \pm 35$

$M = 5.273 \pm 0.004$ GeV/c$^2$

$\sigma = 0.046 \pm 0.004$ GeV/c$^2$

CDF Run II Preliminary

$B^+ \to J/\psi K^+$

$\lambda_{ct} = 528 \pm 72$ $\mu$m (stat)

$\lambda_{ct} = 528 \pm 72$ $\mu$m (stat)

D0 Run II Preliminary

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Di-muon: $B$ exclusive lifetime

$B^+ \rightarrow J/\psi K^+$ and $B^0 \rightarrow J/\psi K^{*0}$: control sample for systematics.

Measurements: $\tau(B_s)$, $\tau(B^0)/\tau(B^+)$, $\tau(B_s)/\tau(B_d)$, (+ $\beta_s$ phase)

CDF results

\begin{align*}
\tau_{B^+} &= 1.57 \pm 0.07 \text{ (stat.)} \pm 0.02 \text{ (syst.)} \text{ ps} \\
\tau_{B^0} &= 1.42 \pm 0.09 \text{ (stat.)} \pm 0.02 \text{ (syst.)} \text{ ps} \\
\tau_{B_s} &= 1.26 \pm 0.20 \text{ (stat.)} \pm 0.02 \text{ (syst.)} \text{ ps} \\
\frac{\tau_{B^+}}{\tau_{B^0}} &= 1.11 \pm 0.09 \\
\frac{\tau_{B_s}}{\tau_{B_d}} &= 0.89 \pm 0.15
\end{align*}
Di-muon: opposite-side tagging

Next step: tagging of the B flavor at production

Opposite-side tagging:

✦ semileptonic decay of other $B$: $b \rightarrow c l^{-}\bar{\nu}$
✦ jet charge: $\sum Q_i p_T^i$
✦ kaon tagging

Figures of merit:

$$\epsilon = \frac{N_{\text{correct}} + N_{\text{wrong}}}{N_{\text{correct}} + N_{\text{wrong}} + N_{\text{notag}}}$$

$$D = \frac{N_{\text{correct}} - N_{\text{wrong}}}{N_{\text{correct}} + N_{\text{wrong}}}$$

✦ tag always right: $D = 1$
✦ tag right 50% of the time: $D = 0$

D0 Run-II Preliminary

Soft Muon Tagging

✦ highest $p_T$ muon
✦ $\Delta R(\text{reconstructed } B) > 2$
✦ $p_T > 1.9$ GeV/c

$$\epsilon = 8.2 \pm 2.2\%$$
$$D = 63.9 \pm 30.1\%$$
$$\epsilon D^2 = 3.3 \pm 1.8\%$$

Jet Charge Tagging

✦ tracks away from the $B$
✦ $|Q| > 0.2$

$$\epsilon = 55.1 \pm 4.1\%$$
$$D = 21.0 \pm 10.6\%$$
$$\epsilon D^2 = 2.4 \pm 1.7\%$$

Effective tagging efficiency: $\epsilon D^2$
Lepton + displaced track: semi-leptonic decays

Unbiased sample for tagging studies:
- flavor tagged
- high $B$ contents
- large statistics

Measurements:
- lifetime measurements
- test of HQET+OPE (hadronic mass moments)

CDF Run II Preliminary
Luminosity 60pb$^{-1}$

$B \rightarrow I^+D^-X$

$N(D^+) = 5344 \pm 111$

$B \rightarrow I^+D^0X$

$N(D^0) = 10508 \pm 147$

$B \rightarrow I^+D^{*-}X$

$N(D^{*-}) = 1470 \pm 55$

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Lepton + displaced track: $\Lambda_b$

**Measurement:**
- $\Lambda_b$ lifetime
- $\Lambda_b$ branching ratios
- test of HQET (/ B)

**Proton ID:**
- $dE/dx$ (drift chamber)
- TOF
  - 100 ps @ 140 cm

CDF II Preliminary $\pm 60$ pb$^{-1}$

$\Lambda_b \rightarrow \Lambda_c lv$
$\Lambda_c \rightarrow pK\pi$
Yield: $640 \pm 60$

Yield: $441 \pm 33$

PID on p

CDF RunII Preliminary

$D^+ \rightarrow D^0 \pi$
$D^0 \rightarrow K\pi$
(Pt > 2 GeV/c)

separation = 1.16 $\sigma$

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\[ B_s \rightarrow D_s l\nu X \rightarrow [\phi \pi] l\nu X \rightarrow \left[ \left[ K^+ K^- \right] \pi \right] l\nu X \]

385 ± 22

- high statistics
- lifetime \( \tau(B_s)/\tau(B_d) \)
- mixing:
  - good \( S/N \)
  - partial reconstruction
  - \( \Rightarrow \) limited time resolution
  - \( \Rightarrow \) for moderate \( x_s \)
  - \( \Rightarrow \) back-up sample

CDF RunII Preliminary 60 pb⁻¹

\( N_{D_s} : 385 \pm 22 \)
\( N_{D^+} : 112 \pm 19 \)
Two-track trigger: $B_s$

$B_s \to D_s^{(*)}-\pi^+$, $B_s \to D_s^{(*)}-3\pi$, $B_s \to D_s^{(*)}-D_s^{(*)}+$

golden sample for $B_s$ mixing: resolve fast oscill.

already some channels fully reconstructed: $40 \pm 10 \ D_s$, $65 \pm 20 \ D_s^*$

$B_s \to D_s \pi \to [\phi \pi] \pi \to [[K^+ K^-] \pi] \pi$

$MC: B \to X \to D_s X \to [\phi \pi] X$

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Two-track trigger: $B_s$

$$B^0 \rightarrow D^- \pi^+ \rightarrow [K^+ \pi^- \pi^-] \pi^+$$

- control sample for $B_s \rightarrow D_s^{(*)-} \pi^+$
- $B \rightarrow D \pi$ gives the normalization for $B_s$ branching ratio
  - same trigger
  - same reconstruction

**65 \pm 4 \text{ pb}^{-1} \text{ February 26th 2003 CDF Run 2 PRELIMINARY}**

- **Yield:** 413 ± 40 events
- **Uncorr. Mean:** 5.271 ± 0.002 GeV
- **Sigma:** 20 ± 2 MeV
Two-track trigger: $\Lambda_b$

$\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^- \rightarrow [p^+ K^- \pi^+] \pi^-$

- Lifetime and branching ratios
- No PID

CDF Run 2 PRELIMINARY 65pb$^{-1}$

CDF Run2 PRELIMINARY 65pb$^{-1}$
Two-track trigger: $B \to h^+ h^-$

$B^0_d \to K^+ \pi^-, \pi^+ \pi^-$

$\bar{B}^0_s \to K^+ K^-, K^+ \pi^-$

✦ $B^0 \to \pi^+ \pi^- : \sin 2(\beta + \gamma)$
✦ however: penguin pollution
✦ measuring both $B_d$ and $B_s$
✦ very good signal/noise
✦ rates understood
✦ on-going: disentangle channels (kinematics + $dE/dx$)
✦ direct $CP$ in $B_d \to K \pi$ ?
Conclusion

Detectors understanding and calibration well advanced

Build-up confidence with exclusive $B^+, B^0, \ldots$
First almost competitive analyses: $B_s$ mass, lifetime
Signals seen in many channels for flagship analyses, need more statistics

Displaced track trigger at CDF:
✦ a great success !
✦ very promising for hadronic decays
✦ many more uses ($l + SVT, \ldots$)
✦ access to $\Delta m_s$ via $B_s \rightarrow D_s(3)\pi$
✦ $\Delta \Gamma_s$ via $B_s \rightarrow D_sD_s$ ($+ B_s \rightarrow J/\psi\phi$)

A lot of exciting physics !