Hadronic and semileptonic b-hadron decays at LHCb

Marina Artuso for the LHCb Collaboration
LHCb measurements of the b-hadron cross section

- LHCb measures b-hadron cross section in good agreement with state of the art perturbative QCD calculations (FONNL)

\[
\sigma(pp \rightarrow b\bar{b}X) \quad \text{From } D^0\mu\nu X
\]

<table>
<thead>
<tr>
<th>η</th>
<th>(\sigma(\mu b)) Theory I</th>
<th>(\sigma(\mu b)) Theory II</th>
<th>Measured (\sigma(\mu b))</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,6</td>
<td>89.0</td>
<td>70.2</td>
<td>75.3 ± 5.4 ± 13.0</td>
</tr>
<tr>
<td>All</td>
<td>332</td>
<td>253</td>
<td>284 ± 20 ± 49</td>
</tr>
</tbody>
</table>

\[
\sigma(B^+, 2 < y < 4.5) = 37.1 ± 1.9 \, \text{(stat.)} ± 5.3 \, \text{(syst.)} \, \mu b.
\]

\[
\sigma(pp \rightarrow b\bar{b}X) = 288 ± 4 ± 48 \, \mu b.
\]

Inclusive J/ψ

\[
\sigma(pp \rightarrow b\bar{b}X) = 288 ± 4 ± 48 \, \mu b.
\]


b-hadron production fractions

- b-fractions measured from charm-μ final states:
  - $B^0 + B^+$ mostly $D^0 \mu \nu + D^+ \mu \nu$
  - $B_s$ mostly $D_s \mu \nu$
  - $\Lambda_b$ mostly $\Lambda_c \mu \nu$

- taking into account all the possible cross-feeds:
  - $D^{0, \pm} K \mu \nu (B^0, B^+, B_s)$
  - $D_s K (B^0, B^+, B_s)$
  - $D^0 p(n) (B^0, B^+, \Lambda_b)$
\[ f_s/(f_u+f_d) = 0.134 \pm 0.004 \text{(stat.)} \quad ^{+0.012}_{-0.011} \text{(sys.)} \]

**Systematic error breakdown**

<table>
<thead>
<tr>
<th>Source</th>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bin dependent errors</td>
<td>1.0</td>
</tr>
<tr>
<td>Charm hadron branching fractions</td>
<td>5.5</td>
</tr>
<tr>
<td>(B_s) semileptonic decay modeling</td>
<td>3.0</td>
</tr>
<tr>
<td>Backgrounds</td>
<td>2.0</td>
</tr>
<tr>
<td>Tracking efficiency</td>
<td>2.0</td>
</tr>
<tr>
<td>Lifetime ratio</td>
<td>1.8</td>
</tr>
<tr>
<td>PID efficiency</td>
<td>1.5</td>
</tr>
<tr>
<td>(B_S^0 \to D^0 K^+ X \mu^- \bar{\nu})</td>
<td>+4.1</td>
</tr>
<tr>
<td>((B^- , B_S^0 ) \to D_s^+ K X \mu^- \bar{\nu})</td>
<td>-1.1</td>
</tr>
<tr>
<td>Total</td>
<td>+5.6</td>
</tr>
<tr>
<td></td>
<td>-7.7</td>
</tr>
</tbody>
</table>

LEP: 0.128 ± 0.012
Tevatron: 0.156 ± 0.026  (HFAG)

\[ f_s/(f_u+f_d) \] doesn’t depend on \(\eta\) or \(p_T\) (charm+\(\mu\))
LHCb determination of $f_s/f_d$

\[
\frac{f_s}{f_d}(D_s \mu \nu X) = 0.268 \pm 0.008^{+0.024}_{-0.022}
\]

LHCb has two other measurements:

\[
\frac{\text{BF}(B_s^0 \rightarrow D^- \pi^+)}{\text{BF}(B^0 \rightarrow D^- K^+)} = 0.250 \pm 0.024(\text{stat}) \pm 0.017(\text{syst}) \pm 0.017(\text{theor})
\]

\[
\frac{\text{BF}(B_s^0 \rightarrow D^- \pi^+)}{\text{BF}(B^0 \rightarrow D^- \pi^+)} = 0.256 \pm 0.014(\text{stat}) \pm 0.019(\text{syst}) \pm 0.026(\text{theor})
\]

We average the 3 LHCb measurements to get [LHCb-CONF-2011-34]

\[
\left\langle \frac{f_s}{f_d} \right\rangle = 0.267^{+0.021}_{-0.020}
\]

<table>
<thead>
<tr>
<th>Source</th>
<th>Error(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistical</td>
<td>2.8</td>
</tr>
<tr>
<td>Experimental</td>
<td>3.3</td>
</tr>
<tr>
<td>Sys (symme)</td>
<td></td>
</tr>
<tr>
<td>B_s \rightarrow D_s K \mu \nu</td>
<td>+3.0 -0.8</td>
</tr>
<tr>
<td>B(D^+ \rightarrow K \pi^+ \pi^-)</td>
<td>2.2</td>
</tr>
<tr>
<td>B(D_s \rightarrow K K^+ \pi^-)</td>
<td>4.9</td>
</tr>
<tr>
<td>B lifetimes</td>
<td>1.5</td>
</tr>
<tr>
<td>B(B^0/B^+ \rightarrow D_s K^-)</td>
<td>1.5</td>
</tr>
<tr>
<td>Theory</td>
<td>1.9</td>
</tr>
</tbody>
</table>
\[
\frac{f_{\Lambda_b}}{(f_u + f_d)}
\]

**f_{\Lambda_b}/(f_u + f_d) not consistent with flat over p_T**

If we fit with straight line, we get

\[
\frac{f_{\Lambda_b}}{f_u + f_d} = (0.404 \pm 0.017 \pm 0.027 \pm 0.105) \times [1 - (0.031 \pm 0.004 \pm 0.003) \times p_T / \text{GeV}]
\]

Systematic error on the scale 26% from \( B(\Lambda_c \rightarrow pK\pi) \)

CDF value \((0.281 \pm 0.012 + 0.011 + 0.128 - 0.056 - 0.056) \langle p_T \rangle_{\text{CDF}} \approx 14.1 \text{ GeV} \)

LEP value \( 0.110 \pm 0.035 \langle p_T \rangle_{\text{LEP}} = 40 \text{ GeV} \)

7/21/2011

Marina Artuso EPS 2011
Goals in hadronic $B$ decays

• Perform precise measurements of 2 body $B_d$ and $B_s$ decays which, in combination with theoretical evaluations of QCD effects [QCD factorization…] and various flavor symmetries, will teach us more about the interplay of strong and electroweak interactions, and elucidate new physics contributions.

• Determine the mixing induce CP asymmetry in $B_s$ decays and other CP violation observables such as the CKM angle $\gamma$
$B_s \rightarrow J/\psi(\pi^+\pi^- \text{ and } K^+K^-)$

- Measurements of mixing induced CP violation in $B_s^0$ decays are of prime importance in probing new physics, most studied channel is

\[ B_s^0 \rightarrow J / \psi \phi \]

but other final state may play a major role such as

\[ B_s^0 \rightarrow J / \psi f_0 \]

more in C.P.Linn's talk
Study of $B_s^0 \rightarrow J/\psi K^+ K^-$ and first observation of $B_s^0 \rightarrow J/\psi f'_2(1525)$

Selecting events with $K^+ K^-$ within ±20 MeV of the $\phi$ mass, we obtain the normalization $J/\psi \phi$ signal

$$R_{eff}^{f'_2} = \frac{N_{corr}(B_s^0 \rightarrow J/\psi f'_2)}{N_{corr}(B_s^0 \rightarrow J/\psi \phi)} = (19.4 \pm 1.8 \pm 1.1)\%$$

Angular analysis shows consistency with spin 2
Study of $m(\pi^+\pi^-)$ from $B_s$ decays

We require $J/\psi \pi^+\pi^-$ to be within ±25 MeV of the $B_s$ mass, and we study the invariant mass of the $\pi^+\pi^-$ system.

$$R_{\text{eff}}^{f_0} = \frac{N_{\text{corr}}(J/\psi f_0)}{N_{\text{corr}}(J/\psi \phi)} = (21.7 \pm 1.1 \pm 1.0)\%$$

Prediction by Stone & Zhang $R_{\text{th}}^{f_0} \approx 20\%$


Cutting on $m(\pi^+\pi^-) = (1200,1600)$

significant D-wave component

$f_0$ mass region $\approx$ s-wave
First observation of $B_c^+ \rightarrow J/\psi \pi^+ \pi^- \pi^+$
Only $3^{rd}$ $B_c^+$ decay mode ever observed

58.2$\pm$9.6 events
6268.4$\pm$1.7 MeV (uncalibrated)
$\sigma$=9.7$\pm$1.6 MeV
6.8$\sigma$

163.1$\pm$15.7 events
6270.3$\pm$1.4 MeV (uncalibrated)
$\sigma$=12.7$\pm$1.6 MeV
11$\sigma$

$\text{BR}(B_c^+ \rightarrow J/\psi \pi^+ \pi^- \pi^+)/\text{BR}(B_c^+ \rightarrow J/\psi \pi^+)=3.0 \pm 0.6 \pm 0.4$

Consistent with the theoretical prediction 2.1$\pm$0.3 (ff uncertainty)
$B_c \to J/\psi \pi \pi \pi$ resonant substructure

- Sideband subtracted signal in the real data
- MC $B_c \to J/\psi a_1(1260)$, $a_1(1260) \to \rho(770)\pi$
- No $B_c \to \psi(2S)\pi$

same studies have also led to another non-observation of interest, see Yanxi Zhang's presentation tomorrow
First observation of $B_s^0 \rightarrow D^0 K^{*0}$

2010 data 36 pb$^{-1}$

\[
\text{BR}(B \rightarrow D^0 \rho^0) = (3.2 \pm 0.5) \times 10^{-4} \text{ (PDG)}
\]

\[
\text{BR}(B_s \rightarrow D^0 K^{*0}) = (5.14 \pm 1.17 \pm 0.52 \pm 0.64 \pm 0.80) \times 10^{-4}
\]
Conclusions

• LHCb is probing a vast array of b-hadron decays, in search of a better understanding of the Standard Model and new physics signatures:
  – Observed b-production fraction dependence upon event environment
  – New modes to probe $\phi_s$ in $B_s$ decays
  – New $B_s$, $B_c$, $\Lambda_b$ decay modes discovered and many more on the way!
• New theoretical ideas to exploit these data are welcome!