$b$ and $c$ hadron production and spectroscopy at LHCb

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On behalf of the LHCb collaboration

The 19th PASCOS © Taipei, 20~27 Nov 2013
Introduction

Selected results:

- $B$ meson production
- Observation of $B_c^+ \rightarrow B_s \pi^+$ decay
- Observation of $B_c^+ \rightarrow J/\psi K^+ K^- \pi^+$ decay
- $D_J$ meson spectroscopy
- Search for $\Xi_{cc}^+$ baryon

Summary
Various QCD models give different predictions
- \( \sigma_{\text{production}}, M, \tau, Br, \ldots \)
Experimental measurements test these predictions
New states/decay modes provide inputs to theorists

Why at LHCb?
- Large production yields
  - \( \sim 10^{11} \ b\bar{b} \) pairs/yr,
  - 20 times for \( c\bar{c} \)
  - Plenty of \( B_c, b \)-baryons, ...
- Unique kinematic range
  - \( 2 < \eta < 5 \), access to low \( p_T \)
  - Complementary to ATLAS/CMS
- State-of-art detector designed for heavy flavour studies

→ E. Rodrigues’ talk “Summary of flavour physics results” on 21 Nov.
Tests for pQCD calculations

Status:

- Studied by ATLAS ($B^+$) and CMS ($B^+, B^0, B^0_s$)
  
  - ATLAS: $9 < p_T < 120$ GeV, $|y| < 2.25$
  
  - CMS: $p_T > 5$ GeV, $|y| < 2.4$ (for $B^+$)

- $B^+$ production was previously measured at LHCb using 35 pb$^{-1}$ data

- The latest analysis uses 0.36 fb$^{-1}$ @ 7 TeV
  
  - not only for $B^+$ but also for $B^0$ and $B^0_s$
  
  - $0 < p_T < 40$ GeV, $2.0 < y < 4.5$
**B selection with dimuon**

**JHEP08(2013) 117**

0 < $p_T$ < 40 GeV, 2.0 < $y$ < 4.5

\[ \begin{align*}
B^+ & \rightarrow J/\psi K^+; \\
B^0 & \rightarrow J/\psi K^{*0}, K^{*0} \rightarrow K^+\pi^-; \\
B_s^0 & \rightarrow J/\psi \phi, \quad \phi \rightarrow K^+K^-.
\end{align*} \]

Trigger efficiency: $\sim 90\%$ for dimuon channels
Integrated $B$ production $x$-section

$B^+$ production updated with higher statistics, consistent with previous results.

New results for $B^0$ and $B_s^0$ in LHCb kinematic range

$0 < p_T < 40$ GeV, $2.0 < y < 4.5$

Result with 35 pb$^{-1}$ data: $41.4 \pm 1.4$ (stat) $\pm 3.2$ (syst) $\mu$b
Differential production $x$-section

Overall scale fixed using hadronisation fractions $f_{b \to B_{u,d}}, f_{b \to B_s}$ measured by LHCb

Consistent with Fixed-order plus next-to-leading logarithm (FONLL) calculations

$\text{JHEP10}(2012) \ 137$

$\text{PRD85}(2012) \ 032008$
A family of unique mesons consists of different heavy quarks

- Ground state only decays weakly

⇒ a large variety of decay modes expected

Experimentally confirmed channels: $B_c^+ \rightarrow ...$

- $J/\psi \ell^+\ell^-$ observed at Tevatron
  - PRL 109 (2012)232001
  - PRD 87 (2013)071103

- $J/\psi \pi^+$
  - PRL 108 (2012)251802
  - PRD 87 (2013)112012

- $J/\psi D_s^{(*)+}$
  - JHEP 09(2013) 075
  - arXiv:1309.0587

- $J/\psi K^K-$
  - PRD 87 (2013)181801

- $\psi(2S) \pi^+$
Observation of $B_c^+ \rightarrow J/\psi K^+K^-\pi^+$

- 1 fb$^{-1}$ (7 TeV) + 2 fb$^{-1}$ (8 TeV)

- $m_{KK\pi}$ and $m_{J/\psi KK}$ from $D_s$ and $B_s$ sidebands to avoid contributions from $B_c \rightarrow J/\psi D_s$ or $B_s \pi$

- Largest contribution: $B_c^+ \rightarrow J/\psi \bar{K}^*0 K^+$

\[
\frac{\text{Br}(B_c \rightarrow J/\psi K^+K^-\pi^+)}{\text{Br}(B_c \rightarrow J/\psi \pi^+)} = 0.53 \pm 0.10\text{(stat)} \pm 0.05\text{(syst)}
\]

- In good agreement with theoretical predictions 0.49 and 0.47

*arXiv:1309.0587*

*arXiv: 1307.0953,*
Observation of $B_c^+ \rightarrow B_s^0 \pi^+$

- First observation of $c$ decay in $B_c^+$
- First decay of $B \rightarrow B$ decay
- $\mathcal{L} = 3 \text{ fb}^{-1}$
- $B_s^0$ decaying to two final states: $D_s^- \pi^+$ and $J/\psi \phi$
- Two-stage BDT for successive $B_s$ and $B_c$ selection
\[ B_c^+ \rightarrow B_s^0 \pi^+ \]

\[ D_s^- \pi^+ (D_s^- \rightarrow K^+K^-\pi^-) \]

\[ J/\psi \phi \ (J/\psi \rightarrow \mu^+\mu^-, \phi \rightarrow K^+K^-) \]

\[ B_s^0 \pi^+ \]

7.5 \( \sigma \)

5.5 \( \sigma \)

PRL 111(2013)181801
Combining \((D_s^- \pi^+)_{B_s} \pi^+\) and \((J/\psi \phi)_{B_s} \pi^+\):

\[
\frac{\sigma(B_c^+)}{\sigma(B_s^0)} \times \mathcal{B}(B_c^+ \to B_s^0 \pi^+) = (2.37 \pm 0.31 \text{ (stat)} \pm 0.11 \text{ (syst)}^{+0.17}_{-0.13} (\tau_{B_c^+})) \times 10^{-3}
\]

Theory predicts \(\mathcal{B}(B_c^+ \to J/\psi \pi^+) \sim 0.15\%\)

\[
\frac{\sigma(B_c^+)}{\sigma(B_s^0)} \times \mathcal{B}(B_c^+ \to J/\psi \pi^+) \times f_s/f_d \text{ measured at LHCb}
\]

\[
\Rightarrow \sigma(B_c^+ \to B_s \pi) \sim 0.02
\]

\[
\Rightarrow \mathcal{B}(B_c \to B_s \pi) \sim 10\%, \text{ largest for any known } B \text{ meson weak decay}
\]
Excited $D$ mesons

- Quark model predicts many excited $D_J$ states
- Only a few are well established
- Search for new states using $1.0 \text{ fb}^{-1}$ data @ 7 TeV
  
  - $D_J \to D^+\pi^-$, $D^0\pi^+$ and $D^{*+}\pi^-$ ($D^{*+} \to D^0\pi^+$)  

$\begin{array}{c}
\begin{array}{c}
\text{Well-established} \\
\text{states}
\end{array}
\end{array}$

- $D_1^*(2618) \quad 1^-$
- $D_0(2558) \quad 0^-$
- $D_2(2801) \quad 2^-$
- $D_3^*(2806) \quad 3^-$
- $D_2^*(2806) \quad 2^-$
- $D_1^*(2796) \quad 1^-$
- $D_4^*(3084) \quad 4^+$
- $D_3(3079) \quad 3^+$
- $D_3(3074) \quad 3^+$
- $D_2^*(3074) \quad 2^+$

- $D^*(2479) \quad 2^+$
- $D_1(2469) \quad 1^+$
- $D_4(2419) \quad 1^+$
- $D_0^*(2380) \quad 0^+$

$\text{Godfrey and Isgur, PRD 32(1985) 189}$

$\text{JHEP 09(2013) 145}$
Resonances decaying to $D^{*+}\pi^- (D^{*+} \rightarrow D^0\pi^+)$ are divided by helicity angle distribution.

**Natural parity**

$P = (-1)^J$

$J^P = 0^+, 1^-, 2^+ ...$

$$d\sigma \propto \sin^2\theta_H$$

**Unnatural parity**

$P = (-1)^{J+1}$

$J^P = 0^-, 1^+, 2^- ...$

$$d\sigma \propto 1 + h \cos^2\theta_H \ (h > 0)$$

$|\cos\theta_H| < 0.5$:
Natural parity states are more prominent

$|\cos\theta_H| > 0.5$:
Unnatural parity states are more prominent
$D_1(2420)^0$, $D_2^*(2460)^0$

$D^{*+}\pi^-$ invariant mass spectrum, 1 fb$^{-1}$ @ 7 TeV

\[ |\cos\theta_H| > 0.5 \quad \text{or} \quad |\cos\theta_H| < 0.5 \]

$D_1(2420)^0$, $D_2^*(2460)^0$: well-established states, with $J^P = 1^+$ and $2^+$ respectively

Both confirmed in $D^{*+}\pi^-$, angular analysis results consistent with known $J^P$

$D_1(2420)^0$: unnatural parity

$D_2^*(2460)^0$: natural parity
New $D_J$ resonances in $D^{*+}\pi^-$

$|\cos\theta_H| > 0.5$

$|\cos\theta_H| < 0.5$

$D_J(2580)^0, D_J(2740)^0, D_J(3000)^0$

$D_J^*(2650)^0, D_J^*(2760)^0$

More resonances in $D^{*+}\pi^-$

- Two natural parity states:
  - $D_J^*(2650)^0, D_J^*(2760)^0$

- Three unnatural parity states:
  - $D_J(2580)^0, D_J(2740)^0, D_J(3000)^0$

All observed with significance $>5\sigma$

Properties for all states are uncertain

To determine $J^P$, studies needed in decay from $B$

Consistent with BaBar

$PRD$ 82 (2010) 111101

Possible assignment:
- $D_J(2580)^0$: $0^-$ ($2S D_0(2558)$)
- $D_J^*(2650)^0$: $1^-$ ($2S D_J^*(2618)$)
- $D_J(2740)^0$: $2^-$ ($1D D_2(2801)$)
\( D_j \) in \( D^+ \pi^- \) and \( D^0 \pi^+ \)

- \( D^+ \pi^- \) and \( D^0 \pi^+ \) spectra affected by cross-feeds from \( D^{*+} \pi^- \). In both final states:
  - \( D_2^*(2460) \) are confirmed, and found to have natural parity, consistent with \( J^P = 2^+ \)
  - \( D_j^*(2760), D_j^*(3000) \) observed (> 5\( \sigma \))
  - Precise quantum numbers cannot be determined

\( D_j^*(2760) \) could have \( 2^- \) (1D \( D_1^*(2976) \))

**c hadron**
**$\Xi_{cc}^+$ baryon**

$J^P = \frac{3}{2}^+$

SELEX claimed observation of $\Xi_{cc}^+$ in $\Lambda_c^+ K^- \pi^+$ and $p D^+ K^-$
- $m = 3519$ MeV/c$^2$
- $\tau < 30$ fs @ 90% CL

*PRL 89(2002) 112001, PLB 628(2005) 18*

Not confirmed by FOCUS, BaBar or Belle

- Predicted by quark model
  - $m \sim [3500, 3700]$ MeV/c$^2$
  - $\tau \sim [100, 250]$ fs
- Expected cross-section at LHCb: $\mathcal{O}(10^2)$ nb
Search for $\Xi_{cc}^+$

- Search for $\Xi_{cc}^+ \rightarrow \Lambda_c^+ K^- \pi^+$, ($\Lambda_c^+ \rightarrow pK^- \pi^+$) with 0.65 fb$^{-1}$ data @ 7 TeV

- No significant signal

- Upper limits for production cross-section as a function of $\delta m$ for various lifetime assumptions

$$R = \frac{\sigma(\Xi_{cc}^+)}{\sigma(\Lambda_c^+)} \times \mathcal{B}(\Xi_{cc}^+ \rightarrow \Lambda_c^+ K^- \pi^+)$$

$arXiv: 1310.2538$

\[\delta m = m_{\Lambda_c^+ K^- \pi^+} - m_{\Lambda_c^+} - m_{K^-} - m_{\pi^+}\]
Summary

- LHCb has been fruitful in $b$ and $c$ hadron production and spectroscopy with the data collected in the first stage of LHC operation
  - $B$ production studied in unique kinematic range
  - Many new $B_c^+$ decay channels observed, incl. first $c$ decay
  - New $D_J$ mesons observed
  - Upper limits given for $E_{cc}^+$ production
- Many more results are not covered due to time constraint
- Analyses on 3 fb$^{-1}$ data still ongoing, more excitement to come!
BACKUP
Inclusive $b\bar{b}$ and $c\bar{c}$ production

7 TeV, in LHCb acceptance:

$$\sigma_{b\bar{b}} = 75.5 \pm 14.1 \, \mu b \quad \text{Phys. Lett. B694, 209}$$
$$\sigma_{c\bar{c}} = 1419 \pm 134 \, \mu b \quad \text{Nucl. Phys. B871, 1}$$
### Trigger efficiencies of $B^+$ mesons

Table 55: Trigger efficiencies (in %) for $B^+ \to J/\psi K^+$ in bins of $B$ $p_T$ and $y$.

<table>
<thead>
<tr>
<th>$p_T$ (GeV/c) x $y$</th>
<th>2.0 &lt; $y$ &lt; 2.5</th>
<th>2.5 &lt; $y$ &lt; 3.0</th>
<th>3.0 &lt; $y$ &lt; 3.5</th>
<th>3.5 &lt; $y$ &lt; 4.0</th>
<th>4.0 &lt; $y$ &lt; 4.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>(0.0, 0.5)</td>
<td>29.9 ± 0.2</td>
<td>53.9 ± 0.4</td>
<td>63.0 ± 0.4</td>
<td>64.7 ± 0.4</td>
<td>69.2 ± 0.4</td>
</tr>
<tr>
<td>(0.5, 1.0)</td>
<td>35.3 ± 0.2</td>
<td>52.6 ± 0.2</td>
<td>63.0 ± 0.3</td>
<td>65.7 ± 0.3</td>
<td>69.3 ± 0.3</td>
</tr>
<tr>
<td>(1.0, 1.5)</td>
<td>36.0 ± 0.1</td>
<td>52.7 ± 0.2</td>
<td>62.6 ± 0.2</td>
<td>66.5 ± 0.2</td>
<td>69.8 ± 0.2</td>
</tr>
<tr>
<td>(1.5, 2.0)</td>
<td>37.3 ± 0.1</td>
<td>52.4 ± 0.2</td>
<td>62.5 ± 0.2</td>
<td>66.6 ± 0.2</td>
<td>70.1 ± 0.2</td>
</tr>
<tr>
<td>(2.0, 2.5)</td>
<td>38.8 ± 0.1</td>
<td>53.4 ± 0.2</td>
<td>63.6 ± 0.2</td>
<td>67.3 ± 0.2</td>
<td>71.0 ± 0.2</td>
</tr>
<tr>
<td>(2.5, 3.0)</td>
<td>42.2 ± 0.1</td>
<td>55.5 ± 0.2</td>
<td>64.7 ± 0.2</td>
<td>68.6 ± 0.2</td>
<td>70.8 ± 0.2</td>
</tr>
<tr>
<td>(3.0, 3.5)</td>
<td>42.7 ± 0.1</td>
<td>57.1 ± 0.2</td>
<td>65.4 ± 0.2</td>
<td>69.6 ± 0.2</td>
<td>71.7 ± 0.2</td>
</tr>
<tr>
<td>(3.5, 4.0)</td>
<td>46.5 ± 0.1</td>
<td>58.0 ± 0.1</td>
<td>67.0 ± 0.2</td>
<td>70.9 ± 0.2</td>
<td>73.0 ± 0.2</td>
</tr>
<tr>
<td>(4.0, 4.5)</td>
<td>47.8 ± 0.1</td>
<td>60.3 ± 0.1</td>
<td>68.4 ± 0.1</td>
<td>72.5 ± 0.2</td>
<td>73.8 ± 0.2</td>
</tr>
<tr>
<td>(4.5, 5.0)</td>
<td>49.4 ± 0.1</td>
<td>62.1 ± 0.1</td>
<td>70.2 ± 0.2</td>
<td>73.5 ± 0.2</td>
<td>74.7 ± 0.2</td>
</tr>
<tr>
<td>(5.0, 5.5)</td>
<td>50.7 ± 0.1</td>
<td>64.0 ± 0.1</td>
<td>71.4 ± 0.2</td>
<td>74.8 ± 0.2</td>
<td>75.9 ± 0.2</td>
</tr>
<tr>
<td>(5.5, 6.0)</td>
<td>52.5 ± 0.1</td>
<td>64.8 ± 0.1</td>
<td>72.6 ± 0.1</td>
<td>76.3 ± 0.1</td>
<td>76.9 ± 0.1</td>
</tr>
<tr>
<td>(6.0, 6.5)</td>
<td>55.5 ± 0.1</td>
<td>66.7 ± 0.1</td>
<td>73.8 ± 0.1</td>
<td>77.1 ± 0.1</td>
<td>77.7 ± 0.1</td>
</tr>
<tr>
<td>(6.5, 7.0)</td>
<td>56.7 ± 0.1</td>
<td>68.2 ± 0.1</td>
<td>74.7 ± 0.1</td>
<td>77.9 ± 0.2</td>
<td>78.8 ± 0.2</td>
</tr>
<tr>
<td>(7.0, 7.5)</td>
<td>58.7 ± 0.1</td>
<td>69.9 ± 0.1</td>
<td>75.7 ± 0.1</td>
<td>78.6 ± 0.2</td>
<td>79.5 ± 0.2</td>
</tr>
<tr>
<td>(7.5, 8.0)</td>
<td>59.8 ± 0.1</td>
<td>71.0 ± 0.1</td>
<td>76.0 ± 0.2</td>
<td>79.3 ± 0.2</td>
<td>80.6 ± 0.2</td>
</tr>
<tr>
<td>(8.0, 8.5)</td>
<td>62.0 ± 0.1</td>
<td>72.4 ± 0.1</td>
<td>77.1 ± 0.1</td>
<td>79.7 ± 0.2</td>
<td>80.7 ± 0.2</td>
</tr>
<tr>
<td>(8.5, 9.0)</td>
<td>61.7 ± 0.1</td>
<td>73.8 ± 0.1</td>
<td>77.7 ± 0.2</td>
<td>80.1 ± 0.2</td>
<td>82.0 ± 0.2</td>
</tr>
<tr>
<td>(9.0, 9.5)</td>
<td>63.0 ± 0.1</td>
<td>74.4 ± 0.1</td>
<td>78.4 ± 0.1</td>
<td>80.8 ± 0.2</td>
<td>81.9 ± 0.2</td>
</tr>
<tr>
<td>(9.5, 10.0]</td>
<td>64.5 ± 0.1</td>
<td>74.7 ± 0.1</td>
<td>79.0 ± 0.2</td>
<td>81.2 ± 0.2</td>
<td>83.0 ± 0.2</td>
</tr>
<tr>
<td>(10.0, 10.5]</td>
<td>66.4 ± 0.1</td>
<td>75.3 ± 0.1</td>
<td>79.1 ± 0.2</td>
<td>80.9 ± 0.2</td>
<td>82.8 ± 0.2</td>
</tr>
<tr>
<td>(10.5, 11.5]</td>
<td>67.3 ± 0.2</td>
<td>76.3 ± 0.2</td>
<td>79.6 ± 0.2</td>
<td>81.2 ± 0.2</td>
<td>83.1 ± 0.2</td>
</tr>
<tr>
<td>(11.5, 12.5]</td>
<td>67.6 ± 0.2</td>
<td>76.7 ± 0.2</td>
<td>79.4 ± 0.2</td>
<td>81.0 ± 0.2</td>
<td>83.3 ± 0.2</td>
</tr>
<tr>
<td>(12.5, 14.0]</td>
<td>69.2 ± 0.2</td>
<td>77.4 ± 0.2</td>
<td>79.8 ± 0.2</td>
<td>80.7 ± 0.2</td>
<td>82.9 ± 0.2</td>
</tr>
<tr>
<td>(14.0, 16.5]</td>
<td>70.1 ± 0.2</td>
<td>78.6 ± 0.2</td>
<td>80.0 ± 0.2</td>
<td>80.0 ± 0.2</td>
<td>82.3 ± 0.2</td>
</tr>
<tr>
<td>(16.5, 23.5]</td>
<td>71.1 ± 0.3</td>
<td>80.1 ± 0.3</td>
<td>80.3 ± 0.3</td>
<td>79.1 ± 0.3</td>
<td>74.8 ± 0.3</td>
</tr>
<tr>
<td>(23.5, 40.0]</td>
<td>71.7 ± 0.4</td>
<td>81.5 ± 0.4</td>
<td>80.5 ± 0.4</td>
<td>77.5 ± 0.4</td>
<td>68.7 ± 0.4</td>
</tr>
</tbody>
</table>
Excited $D_J$:
resonance parameters, yields and significance

<table>
<thead>
<tr>
<th>Resonance</th>
<th>Final state</th>
<th>Mass (MeV)</th>
<th>Width (MeV)</th>
<th>Yields $\times 10^3$</th>
<th>Significance ($\sigma$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_1(2420)^0$</td>
<td>$D^{*+}\pi^-$</td>
<td>$2419.6 \pm 0.1 \pm 0.7$</td>
<td>$35.2 \pm 0.4 \pm 0.9$</td>
<td>$210.2 \pm 1.9 \pm 0.7$</td>
<td></td>
</tr>
<tr>
<td>$D_2(2460)^0$</td>
<td>$D^{*+}\pi^-$</td>
<td>$2460.4 \pm 0.4 \pm 1.2$</td>
<td>$43.2 \pm 1.2 \pm 3.0$</td>
<td>$81.9 \pm 1.2 \pm 0.9$</td>
<td></td>
</tr>
<tr>
<td>$D_s^*(2650)^0$</td>
<td>$D^{*+}\pi^-$</td>
<td>$2649.2 \pm 3.5 \pm 3.5$</td>
<td>$140.2 \pm 17.1 \pm 18.6$</td>
<td>$50.7 \pm 2.2 \pm 2.3$</td>
<td>$24.5$</td>
</tr>
<tr>
<td>$D_J^*(2760)^0$</td>
<td>$D^{*+}\pi^-$</td>
<td>$2761.1 \pm 5.1 \pm 6.5$</td>
<td>$74.4 \pm 3.4 \pm 37.0$</td>
<td>$14.4 \pm 1.7 \pm 1.7$</td>
<td>$10.2$</td>
</tr>
<tr>
<td>$D_J(2580)^0$</td>
<td>$D^{*+}\pi^-$</td>
<td>$2579.5 \pm 3.4 \pm 5.5$</td>
<td>$177.5 \pm 17.8 \pm 46.0$</td>
<td>$60.3 \pm 3.1 \pm 3.4$</td>
<td>$18.8$</td>
</tr>
<tr>
<td>$D_J(2740)^0$</td>
<td>$D^{*+}\pi^-$</td>
<td>$2737.0 \pm 3.5 \pm 11.2$</td>
<td>$73.2 \pm 13.4 \pm 25.0$</td>
<td>$7.7 \pm 1.1 \pm 1.2$</td>
<td>$7.2$</td>
</tr>
<tr>
<td>$D_J(3000)^0$</td>
<td>$D^{*+}\pi^-$</td>
<td>$2971.8 \pm 8.7$</td>
<td>$188.1 \pm 44.8$</td>
<td>$9.5 \pm 1.1$</td>
<td>$9.0$</td>
</tr>
<tr>
<td>$D_2^*(2460)^0$</td>
<td>$D^{+}\pi^-$</td>
<td>$2460.4 \pm 0.1 \pm 0.1$</td>
<td>$45.6 \pm 0.4 \pm 1.1$</td>
<td>$675.0 \pm 9.0 \pm 1.3$</td>
<td></td>
</tr>
<tr>
<td>$D_J^*(2760)^0$</td>
<td>$D^{+}\pi^-$</td>
<td>$2760.1 \pm 1.1 \pm 3.7$</td>
<td>$74.4 \pm 3.4 \pm 19.1$</td>
<td>$55.8 \pm 1.3 \pm 10.0$</td>
<td>$17.3$</td>
</tr>
<tr>
<td>$D_J^*(3000)^0$</td>
<td>$D^{+}\pi^-$</td>
<td>$3008.1 \pm 4.0$</td>
<td>$110.5 \pm 11.5$</td>
<td>$17.6 \pm 1.1$</td>
<td>$21.2$</td>
</tr>
<tr>
<td>$D_2^*(2460)^+$</td>
<td>$D^0\pi^+$</td>
<td>$2463.1 \pm 0.2 \pm 0.6$</td>
<td>$48.6 \pm 1.3 \pm 1.9$</td>
<td>$341.6 \pm 22.0 \pm 2.0$</td>
<td></td>
</tr>
<tr>
<td>$D_J^*(2760)^+$</td>
<td>$D^0\pi^+$</td>
<td>$2771.7 \pm 1.7 \pm 3.8$</td>
<td>$66.7 \pm 6.6 \pm 10.5$</td>
<td>$20.1 \pm 2.2 \pm 1.0$</td>
<td>$18.8$</td>
</tr>
<tr>
<td>$D_J^*(3000)^+$</td>
<td>$D^0\pi^+$</td>
<td>$3008.1$ (fixed)</td>
<td>$110.5$ (fixed)</td>
<td>$7.6 \pm 1.2$</td>
<td>$6.6$</td>
</tr>
</tbody>
</table>