Heavy Flavor Production at LHCb

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August 1, 2017
• fully instrumented between $2 < \eta < 5$
• momentum resolution between 0.5% at 5 GeV to 1% at 200 GeV
• impact parameter resolution of $13 - 20 \mu m$ for tracks
• secondary vertex precision of $0.01 - 0.05(0.1 - 0.3) \text{ mm in } xy(z)$
Introduction

Trigger

- real-time calibration and full event reconstruction in Run 2
- inclusive dimuon from threshold and jet triggers in Run 2
- full detector readout in Run 3
Heavy Flavor Jets
Heavy Flavor Tagging

LHCb, JINST 10 (2015)

### Figures

#### Figure 1: BDT Plots
- **LHCb Data:**
  - b (red)
  - c (green)
  - udsg (blue)

#### Figure 2: D+Jet Distribution
- **LHCb Data:**
  - b (red)
  - c (green)
  - udsg (blue)

### Diagrams

- **PV:** Pseudorapidity vertex
- **SV:** Secondary vertex
- **Jet:** Hadron jet
- **p:** Particle momentum
Heavy Flavor with Leptons

- **LHCb, JINST 10 (2015):** validation of performance
- **LHCb, PRD 92 (2015):** $W + c$ and $W + b$ measurement
- **LHCb, PRL 115 (2015):** first forward top measurement
- **LHCb, PLB 767 (2017):** $t\bar{t}$, $W + c\bar{c}$, and $W + b\bar{b}$
Top Results

LHCb, PRL 115 (2015)

$N(W+b)$

$p_T(\mu+b)$ [GeV]

Charge Asymmetry

$\frac{\text{exp} - \text{thr}}{\text{max}(\delta_{\text{thr}})}$

theory from MCFM

7 TeV: $239 \pm 53 \pm 41$ [fb]

8 TeV: $289 \pm 43 \pm 49$ [fb]
$W + \text{jet Results}$

$LHCb, PRD 92 (2015)$

- $-0.09 \pm 0.08 \pm 0.04 \ A(W_c)$
- $0.51 \pm 0.20 \pm 0.09 \ A(W_b)$
- $5.80 \pm 0.44 \pm 0.75 \ \sigma(W_c)/\sigma(W_j) \times 10^2$
- $0.66 \pm 0.13 \pm 0.13 \ \sigma(W_b)/\sigma(W_j) \times 10^2$
- $6.61 \pm 0.19 \pm 0.33 \ \sigma(W^-j)/\sigma(Z_j)$
- $10.49 \pm 0.28 \pm 0.53 \ \sigma(W^+j)/\sigma(Z_j)$

- $-0.01 \pm 0.05 \pm 0.04 \ A(W_c)$
- $0.27 \pm 0.13 \pm 0.09 \ A(W_b)$
- $5.62 \pm 0.28 \pm 0.73 \ \sigma(W_c)/\sigma(W_j) \times 10^2$
- $0.78 \pm 0.08 \pm 0.16 \ \sigma(W_b)/\sigma(W_j) \times 10^2$
- $6.02 \pm 0.13 \pm 0.30 \ \sigma(W^-j)/\sigma(Z_j)$
- $9.44 \pm 0.19 \pm 0.47 \ \sigma(W^+j)/\sigma(Z_j)$

theory from MCFM
$W + Q\bar{Q}$ Results

LHCb, $\sqrt{s} = 8$ TeV

- MCFM CT10

\[
\begin{align*}
\sigma(W^++b\bar{b}) & \quad \sigma(W^-+b\bar{b}) \\
\sigma(W^++c\bar{c}) & \quad \sigma(W^-+c\bar{c}) \\
\sigma(t\bar{t}) & 
\end{align*}
\]

Data

- $\sigma_{\text{stat}}$
- $\sigma_{\text{tot}}$

LHCb, PLB 767 (2017)
$J/\psi$ Production in Jets
The Polarization Puzzle

\[ \frac{d\sigma}{dp_T} [\text{nb/(GeV/c)}] \]

\[ p_T(J/\psi) [\text{GeV/c}] \]

\[ \text{JHEP 10 (2015)} \]

\[ \text{EPJC 73 (2013)} \]

\[ \text{LHCb \( \sqrt{s} = 7 \text{ TeV} \)} \]

\[ \text{NLO NRQCD(1)} \]
\[ \text{NLO CS} \]

\[ \text{2.5 < } y < 4.0 \]

\[ \text{colour singlet} \]
\[ \text{colour octet} \]

\[ \text{low } p_T \]
\[ \text{high } p_T \]

\[ \text{longitudinal polarized} \]
\[ \text{transverse polarized} \]
Signal Determination

- determine $J/\psi$ signal yield with mass fits
- separate prompt from displaced yields with pseudo-lifetime fits

\[ \tilde{\tau} \equiv (x_z - x_z(PV))m/p_z \]
Results

- displaced results can help tune $b$-fragmentation
- LO NRQCD predictions do not match prompt results
- DPS plays an important role, can explain low $z$ behavior
- NLO* NRQCD cannot explain high $z$ behavior
Outlook
Outlook

- robust and efficient $c(b)$-tagging algorithm validated against data
- could see strange asymmetries at end of Run 2
- strong constraints on high-$x$ gluon from top
- top asymmetries should be observable by end of Run 3

- exciting new quarkonia physics underway
- new methods to directly test heavy flavor splitting

Thank you!
Backup
Datasets

V. Vagnoni (2015) HL-LHC

- **projected luminosity per run**

<table>
<thead>
<tr>
<th>LHC era</th>
<th>HL-LHC era</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1(a) 2011</td>
<td>Run 4 2027 - 2029</td>
</tr>
<tr>
<td>Run 1(b) 2012</td>
<td>Run 5 2031 - ?</td>
</tr>
<tr>
<td>Run 2 2015 - 2019</td>
<td>Run 3 2021 - 2023</td>
</tr>
<tr>
<td>Run 3 2021 - 2023</td>
<td></td>
</tr>
<tr>
<td>1 fb$^{-1}$</td>
<td>23 fb$^{-1}$</td>
</tr>
<tr>
<td>2 fb$^{-1}$</td>
<td>300 fb$^{-1}$?</td>
</tr>
<tr>
<td>5 fb$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>15 fb$^{-1}$</td>
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- **LHCb upgrade during LS 2**
  - **LHCb-PUB-2014-040**
  - replacement of readouts and photo-detectors for the RICHs
  - replacement of tracking detectors
  - **full software trigger**, see LHCb-TDR-016
    - currently limited by hardware readout at 1 MHz
    - upgrade will read out entire detector at 40 MHz
SoftDrop

$g \to gg$

$g \to c\bar{c}$

$c \to cg$

$g \to ggJ/\psi$

LHCb: $p_T > 20$ GeV, $z_{\text{tag}} > 0.1$, $\eta \in [3, 4]$

c-hadron tag

Pythia

$R = 1.0$

$(0, 0)_c$

$(0, 1)_c$

$(1, 1)_c$

$(0, 1)J/\psi$