Measuring open charm hadron production in proton-proton collisions at $\sqrt{s} = 13$ TeV with the LHCb detector

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Annual IoP HEPP Meeting, 1st April 2015
Aims

- Aim to measure absolute cross-section of $\sigma (pp \rightarrow c\bar{c})$ at $\sqrt{s} = 13$ TeV using data from LHC Run II
- Measure differential production cross-sections of charm hadrons* in bins of $p_T$ and rapidity
- Previously measured at LHCb with $\sqrt{s} = 7$ TeV using 2010 data†
- Possibility to apply analysis to 2012 data to get a $\sqrt{s} = 8$ TeV measurement
- Will present the motivation, methodology and current progress

*D$^0$, D$, D^+_s$, $D^*(2010)^+$, $\Lambda^+_c$, $D^*(2007)^0$, $D^{*+}_s$, $\Sigma^+_c$, $\Sigma^{++}_c$, $\Xi^+_c$ and $\Xi^{++}_c$

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- Excellent primary vertex resolution
  - 13 µm in X/Y direction
  - 71 µm in Z direction
- Excellent momentum resolution
  - 0.5 %@5 GeV
  - 0.8 %@100 GeV
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- Good particle identification
  - $\epsilon_{\text{PID}}(K) \approx 95\%$ with MisID($\pi \rightarrow K$) $\approx 5\%$
  - $\epsilon_{\text{PID}}(\mu) \approx 97\%$ with MisID($\pi \rightarrow \mu$) $\approx 1\text{--}3\%$
Motivations
Comparisons with theoretical models

- Theoretical models are available such as FONLL\(^\dagger\) and GMVFNS\(^\S\)
- Excellent test of QCD dynamics - especially at high rapidity

\[^\S\]Kniehl, B. A. et al. The European Physical Journal C July 2012, 72, 2082.
Neutrino experiments

- Cosmic rays collide with atmospheric nuclei producing charm hadrons
- Decays result is a significant background for neutrino experiments
- Accurately knowing $\sigma (pp \rightarrow c\bar{c})$ is required to quantify this
- 7 TeV at the LHC is equivalent to 26 PeV with a fixed target

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** http://cern.ch/go/l86H.
• The PROSA Collaboration\textsuperscript{††} have preliminary results using LHCb Run 1 results to fit PDFs
• Using the charm and beauty cross-section measurements
• Results in significant improvements in precision

\textsuperscript{††}PROSA 14-001 Impact of the LHCb measurements of forward charm and beauty production on PDFs
Measurement Strategy
How do we calculate the cross-section?

- Measure yield of a decay in bins of transverse momentum and rapidity
- Can then calculate the integrated cross-section in each bin:

\[ \sigma_i (H_c) = \frac{N_i (H_c \rightarrow f + \text{c.c.})}{\epsilon_{i,\text{tot}} (H_c \rightarrow f) \cdot B (H_c \rightarrow f) \cdot L_{\text{int}}} \]

- And estimate the double differential cross-section with:

\[ \frac{\partial^2 \sigma (H_c)}{\partial p_T \partial y} = \frac{\sigma_i (H_c)}{\Delta p_T \Delta y} \]

- Total \( \sigma (pp \rightarrow c\bar{c}) \) calculated by extrapolating to the full 4 \( \pi \) solid angle using Monte Carlo
- Will also measure cross-section ratios between charm hadrons
- And normalised cross-sections in \( p_T-y \) space
Data taking

· Data will be collected during the first 3 weeks of LHC Run 2
· Cross-section decreases exponentially with increasing $p_T$
· Therefore a split trigger strategy will be used:
  · Passthrough trigger used for, high statistics, low $p_T$ region
  · Turbo stream\textsuperscript{**} used for, low statistics, high $p_T$ region

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Selection chain

**All events**

- $p_T > 1000 \text{ MeV}$
- $p > 2000 \text{ MeV}$
- $\chi^2 < 3$
- $\text{IP} \chi^2 > 9$

**Passthrough**

**Vertex quality**
- Mother lifetime
- Daughter momentum
- Daughter PID

**Final selection and BDT**
Selection strategy

Previous 2010 measurement at $\sqrt{s} = 7 \text{ TeV}$

- Cut based selection
- Lower efficiency
- Not uniform across $p_T/y$ space
Selection strategy

Changes for the new 2015 measurement at $\sqrt{s} = 13$ TeV

- Loose cut based preselection
- Main selection performed using a BDT
- Single PID cut used per species
Yield extraction

- Yields are extracted by performing a 2D fit in mass and IP $\chi^2$
- Mass fit is used to evaluate combinatoric background
- IP $\chi^2$ fit is used to quantify secondary signal
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- Mass fit is used to evaluate combinatoric background.
- IP $\chi^2$ fit is used to quantify secondary signal.
- For modes with a soft pion a 3D fit is used, additionally fitting the delta mass of the mother i.e. $\delta m(D^{*+}) = m(D^{*+}) - m(D^0)$.
Status and prospects

- Provisional selections are complete
- Evaluation of efficiencies is on going
- Yield extraction is complete
- Need to develop strategies for evaluating systematic uncertainties
- Can cross-check the new analysis strategy with the 2010 result using $\sqrt{s} = 7$ TeV data taken in 2011
Backup
<table>
<thead>
<tr>
<th>$H_c$</th>
<th>Modes</th>
<th>$H_c$</th>
<th>Mode</th>
</tr>
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</table>
| $D^0$ | $K^− \pi^+$  
       | $K^− \pi^+ \pi^− \pi^+$ | $D^{*+}$ | $D^0 \rightarrow K^− \pi^+ \pi^− \pi^+$ |
| $D^+$ | $K^− \pi^+ \pi^+$  
       | $\phi \rightarrow K^− K^+$ $\pi^+$ | $D^{*0}$ | $D^0 \rightarrow K^− \pi^+ \pi^0$  
       | $D^0 \rightarrow K^− \pi^+ \pi^− \pi^+$ $\pi^0$ |
| $D^+_s$ | $\phi \rightarrow K^− K^+$ $\pi^+$  
       | $\pi^+ \pi^− \pi^+$ | $D^{*+}_s$ | $D^{+_s} \rightarrow \phi \rightarrow K^− K^+$ $\pi^+$ $\gamma$  
       | $D^{+_s} \rightarrow \pi^+ \pi^− \pi^+ \gamma$ |
| $Λ^+_c$ | $pK^− \pi^+$  
       | $pK^− K^+$ or $p\pi^− \pi^+$ | $Σ^+_c$ | $Λ^+_c \pi^−$  
       | $Σ^+_c$ | $Λ^+_c \pi^+$ |
| $Ξ^+_c$ | $pK^− \pi^+$ | $Ξ^+_c$ | $pK^− K^− \pi^+$ |