Production of open charm and beauty states in $p$Pb collisions with LHCb

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Outline

• Open heavy flavor measurements in $p$Pb collisions
• The LHCb detector
• LHCb $p$Pb datasets
• Prompt $D^0$ and $\Lambda_c^+$ production in $p$Pb collisions at 5 TeV
• Upcoming open beauty and charm measurements
• Conclusion
Open heavy flavor in PbPb collisions

- Heavy flavor states are sensitive probes to study the properties of the QGP created in AA collision.
  - Produced in the early stage of the collisions
  - Significant $D^0$ quenching at higher $p_T$ observed in central PbPb collisions
  - Large $\Lambda_c^+/D^0$ ratio measured in mid-central AuAu collisions
  - $b$-hadron measurements becoming available at LHC

- Open heavy flavor in $pA$ collisions provides baseline measurements to disentangle cold nuclear matter effects from effects of hot and dense medium.
Open heavy flavor in $p$Pb collisions

• LHCb well suited to $p$Pb measurements:
  • Heavy flavor measurement down to $p_T = 0$
  • Separation of prompt and $b$-decay components

• Cold Nuclear Matter effects
  • Initial state:
    • Modification of nuclear PDF
    • Color Glass Condensate
  • Multiple scattering or radiation of partons crossing the nucleus
  • Final state

Shadowing

Anti-shadowing

arXiv:1802.05927
LHCb detector

- A single arm forward spectrometer designed for the study of particles containing $c$ or $b$ quark
- Acceptance: $2 < \eta < 5$
- Vertex detector
  - IP resolution $\sim 20 \mu m$
- Tracking system
  - $\frac{\Delta p}{p} = 0.5\% - 1\%$ (5-200 GeV/$c$)
- RICH
  - $K/\pi/p$ separation
- Electromagnetic + hadronic Calorimeters
- Muon systems
LHCb $p$Pb datasets

- Rapidity Coverage
  - $y^*$: rapidity in nucleon-nucleon cms
  - $\gamma_{\text{cms}} = \pm 0.465$
  - Forward: $1.5 < y^* < 4.0$
  - Backward: $-5.0 < y^* < -2.5$
  - Common region: $2.5 < |y^*| < 4.0$

- $\sqrt{s_{\text{NN}}} = 5.02$ TeV (2013)
  - $p$Pb (1.06 nb$^{-1}$) + Pb$p$ (0.52 nb$^{-1}$)

- $\sqrt{s_{\text{NN}}} = 8.16$ TeV (2016)
  - $p$Pb (13.6 nb$^{-1}$) + Pb$p$ (21.8 nb$^{-1}$)
Prompt $D^0$ measurement in $p$Pb at 5 TeV

- Reconstructed through decay channel: $D^0 \rightarrow K^- \pi^+$

- Inclusive $D^0$ mesons from fitting invariant mass dist.:  
  - Signal: Crystal Ball+Gaussian 
  - Background: linear

- Prompt $D^0$ fraction extracted from fitting impact parameter dist.:  
  - Prompt: simulation  
  - $D^0$-from-$b$: simulation  
  - Background: sideband in data

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Prompt $\Lambda_c^+$ measurement in $pPb$ at 5 TeV

- Reconstructed through decay channel $\Lambda_c^+ \rightarrow pK^-\pi^+$
- Inclusive $\Lambda_c^+$ baryons from fitting invariant mass dist.: 
  - Signal: Gaussian
  - Background: linear

Prompt $\Lambda_c^+$ fraction extracted from fitting impact parameter dist.: 
- Prompt: simulation
- $\Lambda_c^+$-from-$b$: simulation
- Background: sideband in data

LHCb-PAPER-2018-021 in preparation
Prompt $D^0$
double-differential cross-section in $p\text{Pb}$

\begin{align*}
\sqrt{s_{\text{NN}}} = 5 \text{ TeV} \\
\text{LHCb}
\end{align*}

Forward:
\begin{align*}
0 < p_T < 10 \text{ GeV/c} \\
1.5 < y^* < 4.0
\end{align*}

\[ \sigma_{\text{forward}} = 230.6 \pm 0.5 \pm 13.0 \text{ mb} \]

\begin{align*}
\sqrt{s_{\text{NN}}} = 5 \text{ TeV} \\
\text{LHCb}
\end{align*}

Backward:
\begin{align*}
0 < p_T < 10 \text{ GeV/c} \\
-5.0 < y^* < -2.5
\end{align*}

\[ \sigma_{\text{backward}} = 252.7 \pm 1.0 \pm 20.0 \text{ mb} \]
Prompt $\Lambda_c^+$
double-differential cross-section in $p$Pb

\[ \frac{d^2\sigma}{dp_T dy^*} \] [mb/(GeV/c²)]

(a) LHCb preliminary $p$Pb $\sqrt{s_{NN}}=5$ TeV
Forward:
2 < $p_T$ < 10 GeV/c
1.5 < $y^*$ < 4.0

\[ \sigma_{\text{forward}} = 32.1 \pm 1.0 \pm 4.1 \text{ mb} \]

(b) LHCb preliminary $p$Pb $\sqrt{s_{NN}}=5$ TeV
Backward:
2 < $p_T$ < 10 GeV/c
-4.5 < $y^*$ < -2.5

\[ \sigma_{\text{backward}} = 27.7 \pm 1.5 \pm 4.5 \text{ mb} \]
Prompt $D^0$ at 5 TeV forward-backward production ratio

- $R_{FB}$ does not need results from $pp$ collisions.
- Compared to Helac-Onia calculations incorporating different nPDFs
  - Model parameterisation constrained by existing LHC $pp$ cross-section measurements
- Consistent with nPDF predictions within uncertainty
- Data show smaller uncertainties than nPDF calculations

$$R_{FB} = \frac{\sigma(+|y^*|, p_T)}{\sigma(-|y^*|, p_T)}$$


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- Data uncertainties comparable to nPDF calculations

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LHCb-PAPER-2018-021 in preparation


5/16/2018
Prompt $D^0$ at 5 TeV nuclear modification factor in $p$Pb

$$R_{p\text{Pb}}(\gamma^*, p_T) = \frac{1}{A} \times \frac{d\sigma_{p\text{Pb}}(\gamma^*, p_T, \sqrt{s_{\text{NN}}})/dx}{d\sigma_{pp}(\gamma^*, p_T, \sqrt{s_{\text{NN}}})/dx}, \quad A=208$$

- $pp$ reference directly measured by LHCb
- $R_{p\text{Pb}}$ suppressed at forward rapidity
  - slight increase with increasing $p_T$
- $R_{p\text{Pb}}$ closer to 1 at backward rapidity
- Measurements consistent with models with nPDF, CGC
- Data has smaller uncertainties than theory
Prompt $D^0$ at 5 TeV nuclear modification factor in $p$Pb

$$R_{p\text{Pb}}(y^*, p_T) = \frac{1}{A} \times \frac{d\sigma_{p\text{Pb}}(y^*, p_T, \sqrt{s_{\text{NN}}})/dx}{d\sigma_{pp}(y^*, p_T, \sqrt{s_{\text{NN}}})/dx}, \ A=208$$

- $pp$ reference directly measured by LHCb
- forward
  - significant suppression
- backward
  - closer to 1
  - hint of enhancement at large rapidity
- Measurements consistent with models with nPDF, CGC
- Data has smaller uncertainties than theory
Charmed baryon/meson production ratio $R_{\Lambda_c^+/D^0}$ at 5 TeV

$$R_{\Lambda_c^+/D^0} = \frac{\sigma_{\Lambda_c^+}(y^*,p_T)}{\sigma_{D^0}(y^*,p_T)}$$

- Sensitive to charm hadronisation mechanisms
- Model based on measured $pp$ cross-section
- nPDF effects mostly cancel
  - EPS09LO & EPS09NLO similar
  - nCTEQ15 slightly lower.
- Slight increase with increasing $p_T$

- **Forward:**
  - Consistent at lower $p_T$
  - Below theories at higher $p_T$

- **Backward:**
  - Consistent for all $p_T$
Charmed baryon/meson production ratio
\( R_{\Lambda_c^+ / D^0} \) at 5 TeV

\[
R_{\Lambda_c^+ / D^0} = \frac{\sigma_{\Lambda_c^+}(y^*,p_T)}{\sigma_{D^0}(y^*,p_T)}
\]

- Sensitive to charm hadronisation mechanisms
- Model based on measured \( pp \) cross-section
- nPDF effects mostly cancel
  - EPS09LO & EPS09NLO similar
  - nCTEQ15 slightly lower
- Flat across \( y^* \)

- **Consistent with theories for all \( y^* \)**

LHCb-PAPER-2018-021 in preparation
Ongoing open heavy flavor measurements at LHCb

- LHCb participated in the 8 TeV $p$Pb data taking during 2016.
- Recorded luminosity in total $\sim 31nb^{-1}$ (20 times more than 2013)
- Increased charm & beauty cross-sections at higher energy
- Measurements of beauty hadrons in $p$Pb (upcoming)
- Precision measurements of charmed hadrons in $p$Pb (ongoing)
Open beauty measurements in $p\mathrm{Pb}$ 8 TeV

- Upcoming results on fully reconstructed $b$ hadrons:
  - $B^+$, $\Lambda_b^0$ cross-sections in $p\mathrm{Pb}$
  - $R_{FB}$ for $B^+$, $\Lambda_b^0$
  - baryon-meson ratio $R_{\Lambda_b^0/B^+}$
  - $R_{p\mathrm{Pb}}$ for $B^+$, $\Lambda_b^0$
Open charm measurements in $p$Pb 8 TeV

- Precision measurements of charmed hadrons in $p$Pb
- Accuracy improvement in $R_{\Lambda_c^+/D^0}$
- Measurements as functions of multiplicity
- Analyses ongoing
Conclusions

- Cross-sections of prompt $D^0$ and $\Lambda_c^+$ in $pPb$ collisions at 5 TeV measured by LHCb
  - Nuclear modification factor of $D^0$ in $pPb$ collisions directly measured
    - Significant $D^0$ suppression in the forward rapidity
    - More precise than theory
  - $R_{FB}$ measured for $D^0$ and $\Lambda_c^+$, results consistent with theoretical calculations
    - $D^0$ more precise than theory
    - $\Lambda_c^+$ uncertainties comparable to nPDF
  - Charmed baryon-to-meson ratio $R_{\Lambda_c^+/D^0}$ measured
    - Consistent with model except high $p_T$ in forward rapidity

- 8 TeV $pPb$ data with high statistics enable exciting new measurements of open heavy flavor in cold nuclear matter
  - Upcoming results on open beauty states
  - Precision measurements of charmed hadrons ongoing
backup
Prompt $D^0$ differential cross-section in $p\text{Pb}$

- Data consistent with nPDF predictions
- Theoretical calculation with Helac-Onia:
  - Fit to existing LHC $pp$ cross-section measurement
  - Incorporate nPDF
- nCTEQ15 under predicts cross-section at lowest $p_T$
- Data more precise than nPDFs