$D^0$ meson production in $p\,\text{Pb}$ and $\text{PbPb}$ collisions at $\sqrt{S_{\text{NN}}} = 5$ TeV with LHCb

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Outline

• The LHCb detector
• $p$Pb data taking and physics motivation
• Prompt $D^0$ production in $p$Pb collisions
• Prospects of $D^0$ measurement in PbPb and fixed-target collisions
• Summary
The LHCb detector

A single arm **general purpose detector** at **forward** rapidity!

*pseudorapidity acceptance* $2 < \eta < 5$

- **Vertex detector**
  - IP resolution $\sim 20\mu m$
  - Decay time resolution $\sim 45$ fs

- **RICH**
  - $\varepsilon(K \rightarrow K) \sim 95$
  - Mis-ID: $\varepsilon(\pi \rightarrow K) \sim 5$

- **Muon system**
  - $\mu$ identification: $\varepsilon(\mu \rightarrow \mu) \sim 97$
  - Mis-ID: $\varepsilon(\pi \rightarrow \mu) \sim 1-3$

- **Tracking system**
  - $\Delta p/p = 0.5\% - 1.0\%$
  - (5 GeV/c – 200 GeV/c)

- **Dipole magnet**
  - Bending power $4\ Tm$

- **Electromagnetic**
  - + hadronic calorimeters

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*X. Zhu, D0 production in LHCb, HP2016*
**pPb data taking in 2013**

- **Asymmetric collision energy**
  - $E_p = 4$ TeV
  - $E_{Pb} = 1.58$ TeV per nucleon
  - $\sqrt{S_{NN}} = 5$ TeV
  - $\gamma_{cms} = \pm 0.465$, nucleon-nucleon cms

- **Rapidity coverage**
  - Rapidity in nucleon-nucleon cms, $y^*$
    - **Forward ($pPb$)**: $1.5 < y^* < 4.0$
    - **Backward (Pbp)**: $-5.0 < y^* < -2.5$
    - Common coverage: $2.5 < |y^*| < 4.0$

- **Integrated luminosity**
  - Forward ($pPb$): $1.1$ nb$^{-1}$
  - Backward (Pbp): $0.5$ nb$^{-1}$
  - **Only 1/10 data used for the preliminary prompt $D^0$ analysis!**
$p$Pb open charm physics

- Open charm states are sensitive probe to the QGP properties in AA collisions
- However, **cold nuclear matter effect** should be quantified in detail first
  - Nuclear parton distribution function
  - Initial stage radiation or energy loss due to soft collisions
  - Final stage hadronic rescatterings
- With the $p$Pb data, LHCb can play important role in understanding cold nuclear matter effect, thanks to its unique capability
  - Open charm measurement down to zero $p_T$ at forward rapidity
  - Separation of prompt and secondary open charm (from $b$ decay)
Prompt $D^0$ measurement in $p$Pb

- Reconstructed through $D^0 \rightarrow K^-\pi^+$ decays
- Simultaneous 2D fit to $D^0$ mass and impact parameter (IP)

$\rightarrow$ Extraction of prompt $D^0$ yields down to zero-$p_T$

**Mass distribution:**
Signal: Crystal Ball
Background: linear function

**IP distribution:**
Prompt Signal: from simulation
$D^0$ from b: from simulation
Background: shape from sidebands

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X. Zhu, $D^0$ production in LHCb, HP2016

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2016/09/24

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LHCb-CONF-2016-003
Prompt $D^0$ total cross-sections in $p$Pb

$\sigma_{\text{forward}}(p_T < 8 \text{ GeV/c}, 1.5 < |y^*| < 4.0) = 237 \pm 1 \pm 15 \text{ mb},$

$\sigma_{\text{forward}}(p_T < 8 \text{ GeV/c}, 2.5 < |y^*| < 4.0) = 124 \pm 1 \pm 8 \text{ mb},$

$\sigma_{\text{backward}}(p_T < 8 \text{ GeV/c}, 2.5 < |y^*| < 5.0) = 259 \pm 3 \pm 19 \text{ mb},$

$\sigma_{\text{backward}}(p_T < 8 \text{ GeV/c}, 2.5 < |y^*| < 4.0) = 174 \pm 2 \pm 13 \text{ mb}.$

<table>
<thead>
<tr>
<th>Source</th>
<th>Relative uncertainty (%)</th>
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<tbody>
<tr>
<td></td>
<td>forward</td>
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<tr>
<td><strong>Correlated between bins</strong></td>
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<tr>
<td>Signal extraction</td>
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<tr>
<td>Tracking</td>
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<td>PID efficiency</td>
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<tr>
<td>Luminosity</td>
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<tr>
<td>$B(D^0 \to K^+\pi^-)$</td>
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<tr>
<td><strong>Uncorrelated between bins</strong></td>
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<tr>
<td>MC Sample size</td>
<td>1.4−6.5</td>
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<tr>
<td>Statistical uncertainty</td>
<td>1.5−16</td>
</tr>
</tbody>
</table>
Prompt $D^0$ double differential cross-section in $p\text{Pb}$

$LHCb$-CONF-2016-003

**Backward:**

$-5.0 < y^* < -2.5$

$p_T < 8$ GeV/c

**Forward:**

$1.5 < y^* < 4.0$

$p_T < 8$ GeV/c
Prompt $D^0$ differential cross-section in $pPb$

Sizable forward-backward asymmetry
Prompt $D^0$ nuclear modification factor in $pPb$

- $R_{pPb}(y^*, p_T) = \frac{1}{A} \times \frac{\sigma_{pPb}(y^*, p_T, \sqrt{s_{NN}})}{\sigma_{pp}(y^*, p_T, \sqrt{s_{NN}})}$, $A=208$

- Prompt $D^0$ cross-section in $pp$ collisions at $\sqrt{s} = 5$ TeV was extrapolated using LHCb measurements at 7 and 13 TeV

![Graph showing the extrapolation of cross-section with different models](image)

**Extrapolated:** $\sigma_{pp}(p_T < 8 \text{ GeV}/c, 2.5 < |y^*| < 4.0) = 713 \pm 95 (\text{LHCb}) \pm 47 (\text{fit model}) \mu b$

- Prompt $D^0$ in $pp$ at $\sqrt{s} = 5$ TeV was measured recently!

**Measured:** $\sigma_{pp}(p_T < 8 \text{ GeV}/c, 2.5 < |y^*| < 4.0) = 943 \pm 2 \pm 49 \mu b$

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**CAUTION:** Preliminary $R_{pPb}$ uses extrapolated $pp$ cross-sections for reference! will be updated soon with the measured $pp$ values!
Prompt $D^0$ nuclear modification factor in $pPb$

- Extrapolated $pp$ data at $\sqrt{s} = 5$ TeV for reference

Prompt $D^0$ nuclear modification factor in $p$Pb

- Extrapolated $pp$ data at $\sqrt{s} = 5$ TeV for reference
- Nuclear modification factor smaller at forward rapidity
- Measurements consistent with theoretical predictions

Prompt $D^0$ forward-backward asymmetry in $p$Pb

- $R_{FB}(|y^*|, p_T) = \frac{\sigma_{pp}(+|y^*|, p_{T}, \sqrt{s_{NN}})}{\sigma_{Pbp}(-|y^*|, p_{T}, \sqrt{s_{NN}})}$

- No need for $pp$ reference, systematic uncertainty largely cancels
- Significant forward-backward asymmetry observed

PbPb data taking in 2015

- LHCb first participated in PbPb run in December 2015
- 24 colliding bunches, integrated luminosity $L = 3 - 5 \, \mu\text{b}^{-1}$
- Minimum bias trigger

https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015

A PbPb event with 1130 reconstructed tracks and a $J/\psi$ candidate
Centrality definition in PbPb

• Energy deposition in ECAL/HCAL are used to define collision centrality
  • Not saturated even for most central collisions
  • Minimal correlation with particle production measurements
  • Tracking may be possible up to \(~15\)k VELO hits (\(100\% - 50\%\) centrality)

https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015
$D^0$ in PbPb (a first look)

Reconstructed through $D^0 \rightarrow K^- \pi^+ + CC$ decays

https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015
Fixed-target experiment with LHCb

**SMOG: System for Measuring Overlap with Gas**

- Inject noble gases (He, Ne, Ar) into the LHCb vertex detector
- fixed-target physics in pA and PbA configuration, covering mid-rapidity!

Bridge the gap from SPS to LHC in a single experiment!
$D^0$ in fixed-target collisions (a first look)

pNe collisions at $\sqrt{s_{\text{NN}}} = 110$ GeV, ~12 hours data taking in 2015

https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015
Summary

- **Prompt $D^0$ in $\sqrt{s_{NN}} = 5$ TeV $pPb$ collisions**
  - Preliminary results on cross-sections, nuclear modification factor, and forward-backward ratio obtained with 1/10 data
  - Sizable forward-backward asymmetry observed, consistent with theoretical predictions
  - Analysis to be updated including full $pPb$ statistics and $\sqrt{s} = 5$ TeV $pp$ data as reference

- **$D^0$ in $\sqrt{s_{NN}} = 5$ TeV PbPb collisions**
  - Clear $D^0$ signals, analysis on-going, results expected up to centralities around 50%

- **$D^0$ in fixed-target collisions**
  - Clear $D^0$ signals, development of methods to exploit the data

- **Outlook**
  - Systematic prompt open charm ($D^+, D^{*+}, D_S^+, \Lambda_c$) analysis in $\sqrt{s_{NN}} = 5$ TeV $pPb$ collisions
  - New $pPb$ data taking at $\sqrt{s_{NN}} = 8$ TeV (high statistics) in 2016
  - Additional fixed-target data taking runs

Thanks and stay tuned!