Charm cross-section activities in HonexComb

LPCC working group on heavy-ions

Jiayin Sun (Università e INFN, Cagliari)
for the HonexComb charm group:
R. G. De Cassagnac, G. Manca, C. Bierlich, J. Sun, J. Metwally, M. Mazzilli, G.M. Innocenti, A. Geiser, Y. Yang

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Introduction

- Objectives: obtain a combined measurement of $\sigma_{\text{tot}}(c\bar{c})$ and $\sigma_{\text{charm}}$ vs. $p_T$ and $y$ using existing published measurements of ALICE, CMS and LHCb at 5 TeV.
  - Understand theory, find “best” description for total charm cross-section
  - Critical input for calculations in AA collisions

- Goals:
  - Collecting in a common database the relevant charm measurements in $pp$ collisions in a consistent ROOT/txt format.
  - Providing summary plots to be used in review papers and summary talks
  - Providing comprehensive comparisons to theoretical calculations in the various rapidity and transverse momentum regions.
  - Encourage the development of dedicated tunes for theoretical calculations (e.g. Pythia) that consider the knowledge acquired after 10 years of charm measurements at the LHC
  - Common and unique inputs for charm differential cross-section vs. $p_T$ and rapidity to be used as input for AA theoretical calculations
  - Provide an estimation of the total charm cross-section, which incorporates the constraints coming from the various LHC experiments
Charm results and combination

- Collection of open charm results in $pp$ collisions at 5 TeV

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Ref. code</th>
<th>Hadronic decays</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALICE</td>
<td>EPJC 79, 388 (2019)</td>
<td>$D^0 \rightarrow K^-\pi^+, D^+ \rightarrow K^-\pi^+\pi^+, D_s^+ \rightarrow \phi\pi^+ \rightarrow K^+K^-\pi^+, D^{*+} \rightarrow D^{0}\pi^+ (\pm \text{c.c.})$</td>
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<td>PLB, v. 782, 2018, p 474-496</td>
<td>$D^0 \rightarrow K^-\pi^+ (\pm \text{c.c.})$</td>
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<tr>
<td>CMS</td>
<td>PLB, v. 803, 2020, 135328</td>
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<tr>
<td>LHCb</td>
<td>JHEP, 147 (2017)</td>
<td>$D^0 \rightarrow K^-\pi^+, D^+ \rightarrow K^-\pi^+\pi^+, D_s^+ \rightarrow \phi\pi^+ \rightarrow K^+K^-\pi^+, D^{*+} \rightarrow D^{0}\pi^+ (\pm \text{c.c.})$</td>
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- Kinematic regions ($D^0$):
  - ALICE: $0 < p_T < 36$ GeV/$c$; $-0.5 < y < 0.5$
  - CMS: $2 < p_T < 100$ GeV/$c$; $-1.0 < y < 1.0$
  - LHCb: $0 < p_T < 10$ GeV/$c$; $2.0 < y < 4.5$ in $\Delta y = 0.5$ bins

- Produce compilation plots of $\sigma_{charm}$ vs. $p_T$ and $y$

- All information collected and accessible in twiki:
  - [https://twiki.cern.ch/twiki/bin/view/Honexcomb/HonexcombCharmSection](https://twiki.cern.ch/twiki/bin/view/Honexcomb/HonexcombCharmSection)
Combination plots for $D^0$

- $D^0$ cross-section in $p_T$ and $y$
- $D^0$ cross-section vs. $y$ in $p_T$ slices
- Next: comparison to Pythia and FONLL event generators…

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- $D^0$ cross-section vs. $y$ in $p_T$ slices
- PYTHIA: SoftQCD with color reconnection (CR) modes.

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Combination plots for $D^+$

- $D^+$ cross-section in $p_T$ and $y$
- $D^+$ cross-section vs. $y$ in $p_T$ slices
- PYTHIA: SoftQCD with color reconnection (CR) modes.

ATL-PHYS-PUB-2017-008
Combination plots for $D^*$

- $D^*$ cross-section in $p_T$ and $y$
- $D^*$ cross-section vs. $y$ in $p_T$ slices
- PYTHIA: SoftQCD with color reconnection (CR) modes.

ATL-PHYS-PUB-2017-008
Combination plots for $D_s^+$

- $D_s^+$ cross-section in $p_T$ and $y$
- $D_s^+$ cross-section vs. $y$ in $p_T$ slices
- PYTHIA: SoftQCD with color reconnection (CR) modes.

**ATL-PHYS-PUB-2017-008**
PYTHIA-data comparison

- Data from ALICE, CMS and LHCb do not cover the full rapidity range, interpolation and extrapolation must be performed to estimate the total charm cross section.
  - PYTHIA and FONLL event generators
  - PYTHIA settings:
    - Parton-shower approach for charm production in very low $p_T$
    - For hard $2 \rightarrow 2$ process use the PYTHIA model for multiparton interactions [PRD 36 (1987) 2019]
    - The only remaining parameter to fix is the charm mass, default value in PYTHIA is 1.5 GeV
  - Scan charm mass from 1.1 to 1.9 GeV, in 0.1 GeV step size. Produce 10M PYTHIA events for each charm mass value.
  - Find the best charm mass value from simultaneous fit to measured charmed hadrons cross-section in $(p_T, y)$ space.
  - Currently, made comparisons for $D^0$, $D^+$ and $D^*$ mesons. Comparison for $D^+_s$ meson is upcoming.
$D^0$ comparison to PYTHIA

- 10M PYTHIA events for each charm mass value ($m_0$) from 1.1 to 1.9 GeV, in 0.1 GeV step.
- Cross-section vs. rapidity in $p_T$ slices
- Using 5TeV $pp$ data from ALICE, CMS and LHCb
$D^+$ comparison to PYTHIA

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**D* comparison to PYTHIA**

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Simultaneous fit

Work in progress

- Simultaneous fit across $D^0$, $D^+$ and $D^*$ to find the best charm mass value ($m_0$).

- Use the same binning as the published data from ALICE/CMS/LHCb, compare each point between data and PYTHIA, calculate $\chi^2$.

- For this plot, using $p_T < 6 \text{ GeV}/c$, ALICE and LHCb points. Using total uncertainty. Fit with a 3rd order polynomial function.

- LHCb points provide most constraint.

- Next steps:
  - Add $D_s^+$, also consider $\Lambda_c^+$
  - Add contribution from CMS data points. Produce more MC at higher $p_T$.
  - Fine tune uncertainty treatment

$m_0$
Comparison with FONLL for $D^0$

*Work in progress*

- **FONLL** settings:
  - PDF: CTEQ 6.6 + unc.
  - mc: $1.5 \pm 0.2$ GeV

- Fragmentation tuned to LEP data

FONLL: NLO + NLL QCD prediction, absolute prediction with uncertainties
Summary

- The project of total charm cross-section from combining ALICE, CMS and LHCb measurements is making good progress.

- Comparisons with theoretical models are ongoing.
  - Working on fixing charm mass parameter for PYTHIA
  - Parallel work on FONLL ongoing

- Extrapolation to obtain total cross-section, with uncertainty determination.

- Preparing paper on data/theory comparisons and total charm cross-section in the next 1-2 months.