Study charm hadronization via $\Lambda_c^+$ and $D_s^+$ production in pp and PbPb collisions with the CMS experiment

Milan Stojanovic
Purdue University
on behalf of the CMS collaboration

Hard Probes 2020, Austin TX, USA
Motivation

- Heavy quarks produced at earliest stages of the collision
  - follow the whole evolution of the system

- Convenient for perturbative calculations

- Studying energy loss mechanism
  - different than light quarks

- Hadronization process
  - $\Lambda_c^+(udc)$ essential for charm quark coalescence (baryon - meson ratio)
  - $D_s^+(cs)$ suitable for studying strangeness enhancement and coalescence
Motivation

- ALICE and LHCb results different for $\Lambda_c^+/D_0$ in pp collisions
  - Different rapidity range?
Motivation

- ALICE and LHCb results different for $\Lambda_c^+/D^0$ in pp collisions
  - Different rapidity range?

- ALICE reported larger ratio in PbPb than in pp & pPb
Motivation

- ALICE and LHCb results different for $\Lambda_c^+/D^0$ in pp collisions
  - Different rapidity range?

- ALICE reported larger ratio in PbPb than in pp & pPb

- ALICE results suggests larger $R_{AA}$ of strange than non-strange D mesons

- STAR results follow the same trend as ALICE
Reconstruction

- Data from 2015 Run:
  - PbPb: 300M Minimum Bias events
  - pp: 2B Minimum Bias events

- $\Lambda_c^+$ reconstruction
  - $\Lambda_c^+ \rightarrow P^+K^-\pi^+$
  - BR $\sim 6.23\%

- $D_s^+$ reconstruction
  - $D_s^+ \rightarrow \varphi\pi^+ \rightarrow K^+K^-\pi^+$
  - BR $\sim 2.3\%$

Milan Stojanovic

Hard Probes 2020
Reconstruction

- Data from 2015 Run:
  - PbPb: 300M Minimum Bias events
  - pp: 2B Minimum Bias events

- $\Lambda_c^+$ reconstruction
  - $\Lambda_c^+ \rightarrow P^+K^-\pi^+$
  - BR ~ 6.23%

- $D_s^+$ reconstruction
  - $D_s^+ \rightarrow \varphi\pi^+ \rightarrow K^+K^-\pi^+$
  - BR ~ 2.3%

- No particle identification → All possible combinations of three charged tracks in an event are taken into account
Reconstruction

- Data from 2015 Run:
  - PbPb: 300M Minimum Bias events
  - pp: 2B Minimum Bias events

- $\Lambda_c^+$ reconstruction
  - $\Lambda_c^+ \rightarrow P^+K^-\pi^+$
  - BR $\sim 6.23\%$

- $D_s^+$ reconstruction
  - $D_s^+ \rightarrow \varphi\pi^+ \rightarrow K^+K^-\pi^+$
  - BR $\sim 2.3\%$

- No particle identification $\rightarrow$ All possible combinations of three charged tracks in an event are taken into account

- $\Lambda_c^+$ measured inclusively, i.e. prompt+nonprompt

- Only prompt $D_s^+$ is measured
Signal Extraction $\Lambda_c$

- Combinatorial background: 3rd order Chebyshev polynomial function

- Signal: Double Gaussian

**$\Lambda_c^+(pp)$**

- **Data**
- Signal+Background
- Background

**$\Lambda_c^+(PbPb)$**

- **Data**
- Signal+Background
- Background

---

**Signal**

- $10 < p_T < 20$ GeV/c
- $|y| < 1$

**Combinatorial background**

- $38$ nb$^{-1}$ (5.02 TeV pp)
- $44$ μb$^{-1}$ (5.02 TeV PbPb)

---

PLB 803 (2020) 135328
Signal Extraction $D_s^+$

- Combinatorial background: 1<sup>st</sup> or 2<sup>nd</sup> order Chebyshev polynomial function

- Signal: Double Gaussian

### CMS-PAS-HIN-18-017

Milan Stojanovic

Hard Probes 2020
Signal Extraction $D_s^+$

- Combinatorial background: 1st or 2nd order Chebyshev polynomial function

- Signal: Double Gaussian

$D_s^+$

$K^+K^-$ mass fit:

- Signal: $D_s^+ \rightarrow \varphi \pi^+ \rightarrow K^+K^-\pi^+$

- Background: $D_s^+ \rightarrow f_0\pi^+ \rightarrow K^+K^-\pi^+$

$D_s^+ \rightarrow K^+\bar{K}^*0 \rightarrow K^+K^-\pi^+$

CMS-PAS-HIN-18-017
Results: $p_T$ spectra

PLB 803 (2020) 135328

- PYTHIA 8 systematically below data
- PYTHIA 8 + CR consistent with pp data
- GM-VFNS Systematically below data for $p_T < 10$ GeV/c
Results: $p_T$ spectra

- **PYTHIA 8** systematically below data
- **PYTHIA 8 + CR** consistent with pp data
- **GM-VFNS** Systematically below data for $p_T < 10$ GeV/c

- **PYTHIA 8** overestimates data at low $p_T$
- **At higher $p_T$ prediction below data**
Indication of $\Lambda_c^+$ suppression in PbPb collision

Suppression larger in central events
Results: $R_{AA}$

**PLB 803 (2020) 135328**

PbPb 44/102 μb$^{-1}$, pp 38 nb$^{-1}$ (5.02 TeV)

- **Indication of $\Lambda_c^+$ suppression in PbPb collision**
- **Suppression larger in central events**

**CMS-PAS-HIN-18-017**

pp 38 nb$^{-1}$, PbPb 44 μb$^{-1}$ (5.02 TeV)

- $D_s^+$ suppressed in PbPb collision
- No significant $p_T$ dependence observed
- PHSD systematically below data
  
  > PRC 93 (2016) 034906
Results: $\Lambda_c^+/D_0$

Similarity between pp & PbPb results suggest that there is no significant coalescence of $\Lambda_c^+$ ($10 < p_T < 20 \text{ GeV/c}$)

- No significant $p_T$ dependence observed

CMS

PbPb 44 $\mu$b$^{-1}$, pp 38 nb$^{-1}$ (5.02 TeV)

| $|y| < 1$ | PbPb | CMS |
|-----------|------|-----|
| Data: Cent. 0-100% | PP: 20% | PbPb: 31% |

Global uncertainty

- No significant $p_T$ dependence observed
Results: $\Lambda_c/D_0$

- Similarity between pp & PbPb results suggest that there is no significant coalescence of $\Lambda_c^+$ ($10 < p_T < 20$ GeV/c)

- No significant $p_T$ dependence observed

- PYTHIA8 underestimates pp data

- PYTHIA8 + color reconnection – good description of data

- Solid line (Catania) - predicts stronger $p_T$ dependence
  - Coalescence + fragmentation

- Dashed line (TAMU) – reasonable description of data for $p_T < 10$ GeV/c
  - Includes charm baryon states beyond PDG
Results: $D_s/D_0$

CMS-PAS-HIN-18-017

- Ratio similar for PbPb and pp collisions
- No significant $p_T$ dependence observed
- PYTHIA8 shape consistent with pp data
- PHSD systematically below pp&PbPb data, but gives a good description of double ratio ($PbPb/pp$)
  - Microscopic transport model w only collision energy loss
  - PRC 93 (2016) 034906
- TAMU consistent with pp data
  - Model includes charm baryon states beyond PDG
  - PLB 795 (2019) 117
Summary

- Production of $\Lambda_c^+$ and $D_s^+$ measured in pp & PbPb collisions
- Suppression of $\Lambda_c^+$ & $D_s^+$ consistent with $D^0$ results in PbPb
- No significant coalescence of $\Lambda_c^+$ observed for $10 < p_T < 20$ GeV/c
- $\Lambda_c^+$ in pp described well by PYTHIA 8 + CR
- TAMU describes $D_s^+/D^0$ ratio well in pp; $\frac{D_s^+/D^0(PbPb)}{D_s^+/D^0(pp)}$ described well by PHSD
- Possible additional constraints to theoretical models
- New analysis ongoing with increased statistics
  - ~13 times more PbPb data
  - ~6 times more pp data
Backup Slides
CMS

$\Lambda_c/D_0$

CMS PbPb 44 $\mu$b$^{-1}$, pp 38 nb$^{-1}$ (5.02 TeV)

| $|y| < 1$ |
|---|
| PbPb |

$\left(\Lambda_c^+ / D_0^+\right)/\left(D_0^+ / D_0^0\right)$

Global uncertainty
- pp: 20%
- PbPb: 31%

ALICE

$\Lambda_c/D_0$

ALICE

0–80% Pb–Pb, $\sqrt{s_{NN}} = 5.02$ TeV, $|y|<0.5$

pp, $\sqrt{s} = 7$ TeV, $|y|<0.5$

(JHEP 04 (2018) 108)

p–Pb, $\sqrt{s_{NN}} = 5.02$ TeV, $-0.96<y<0.04$

(JHEP 04 (2018) 108)
The alternative estimation based on the FONLL calculation for the $B$ hadron cross section

The systematic uncertainty is taken as the difference between the nominal and alternative $A\epsilon$ values.
- pp: 18%
- PbPb: 29% (also considering the effect of $\frac{R_{AA}^{\text{nonprompt}}}{R_{AA}^{\text{prompt}}}$ correction.)

The default PbPb $A\epsilon$:
- Considering $\frac{R_{AA}^{\text{nonprompt}}}{R_{AA}^{\text{prompt}}} = 1.66 \pm 0.38$

The nonprompt fraction passing the selection criteria:
- pp: 28-34% (PYTHIA CUETP8M1 tune)
- 4-7% for the alternative method.