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

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on behalf of the CMS collaboration

ONLINE

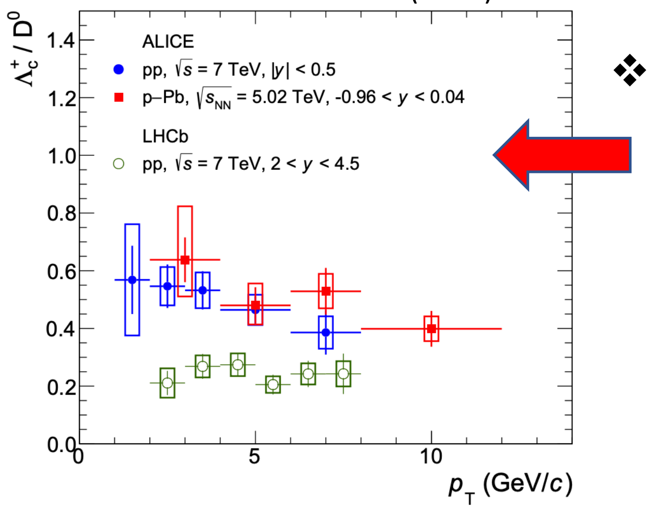
Hard Probes 2020, Austin TX, USA

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

Motivation

JHEP 04 (2018)108



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

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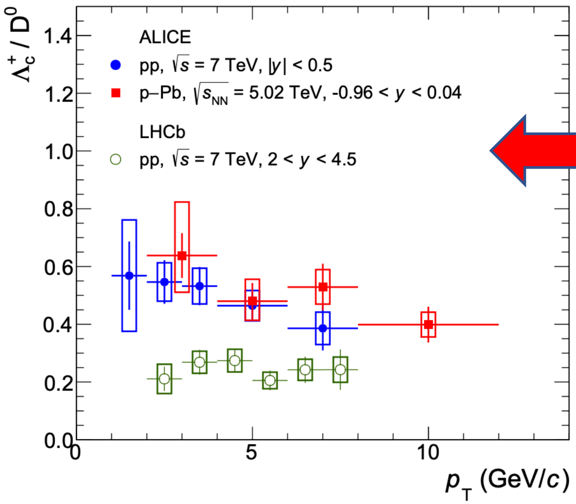

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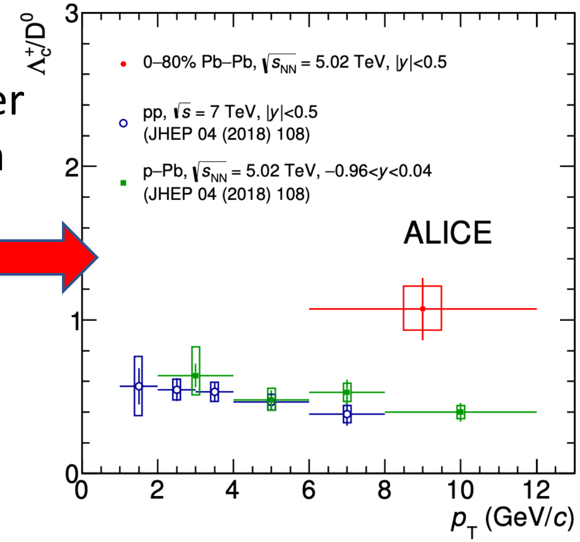
  - ➢ Different rapidity range?

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



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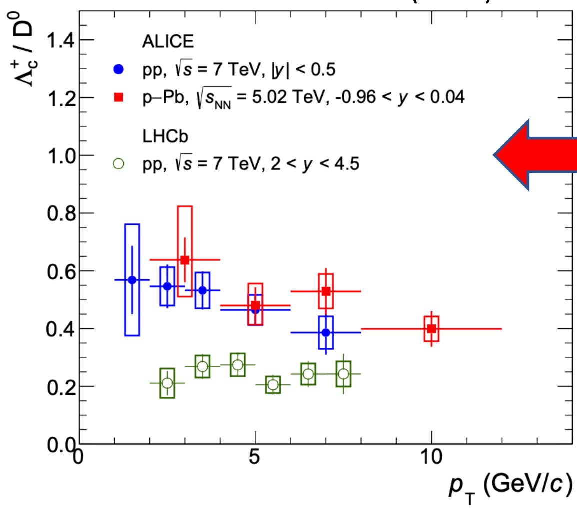

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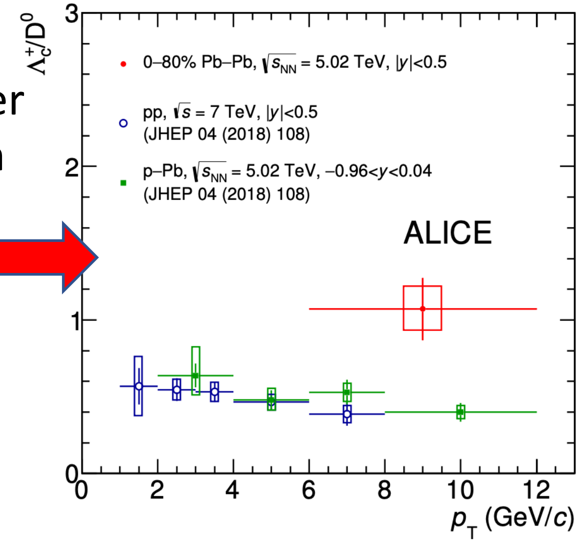

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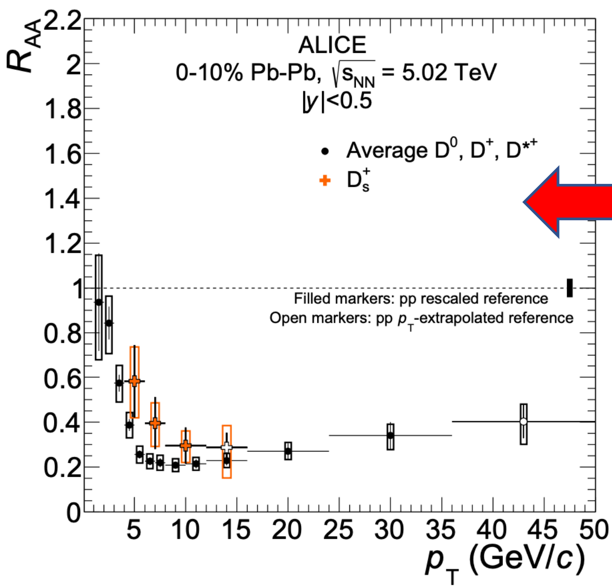


JHEP 1810 (2018) 174

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

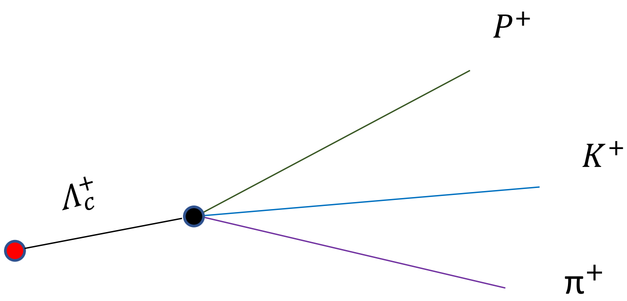
- ❖ STAR results follow the same trend as ALICE

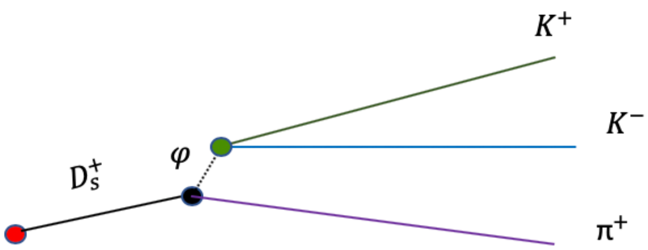
Reconstruction

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

- Λ_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%





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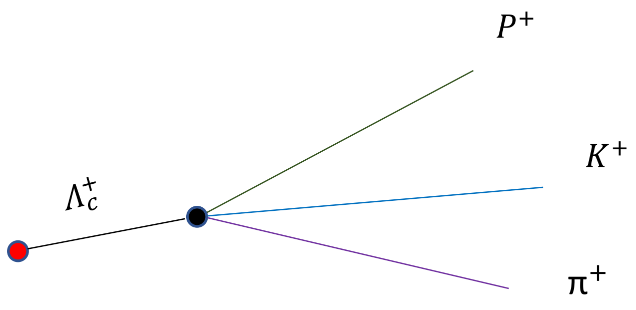
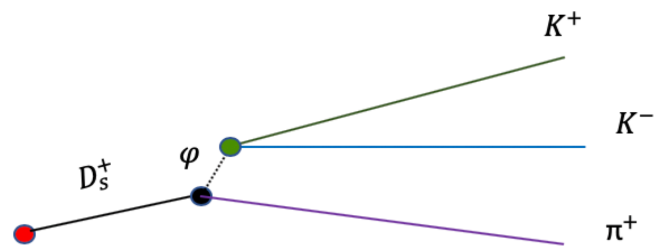
- No particle identification → All possible combinations of three charged tracks in an event are taken into account





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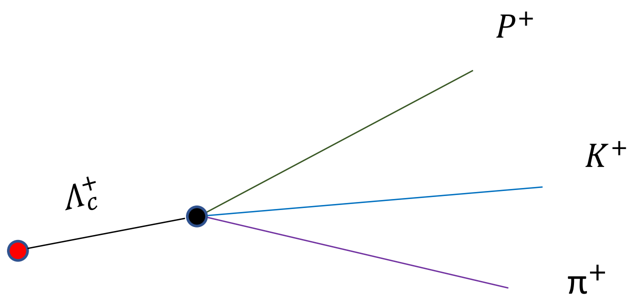

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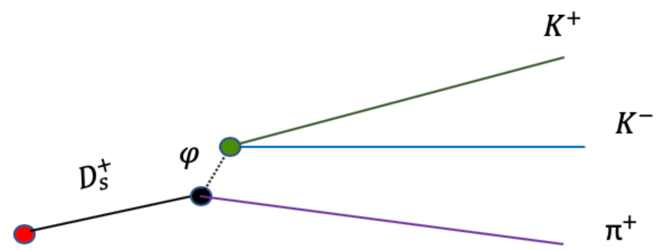

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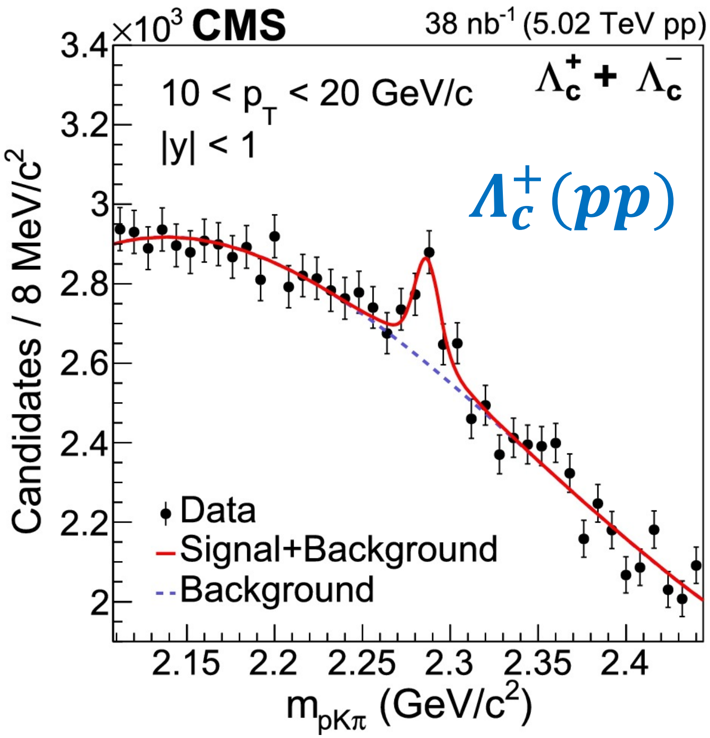
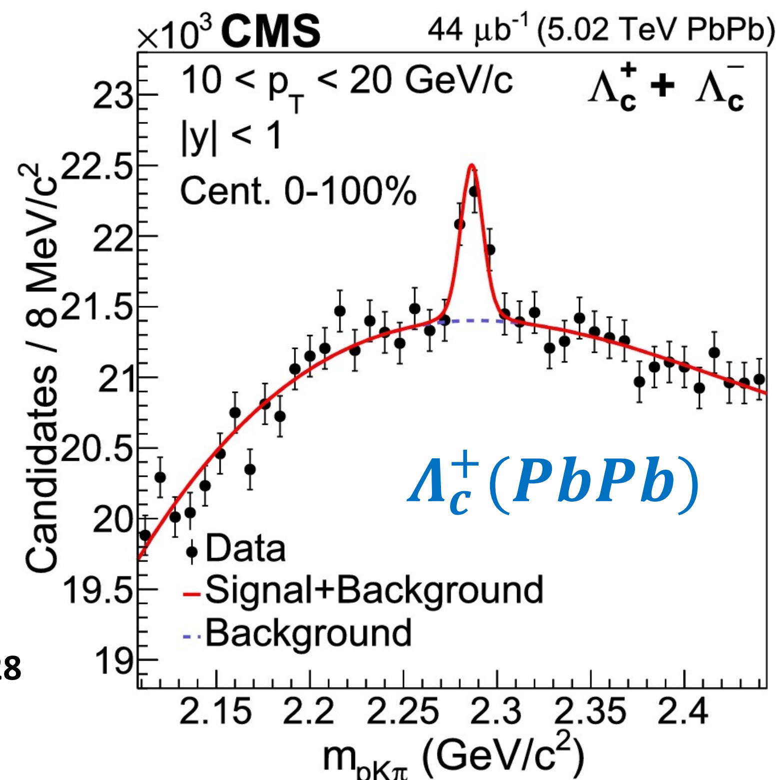
- Λ_c^+ measured inclusively, i.e. prompt+nonpropmpt

- Only prompt D_s^+ is measured

Signal Extraction Λ_c



- Combinatorial background: 3rd order Chebyshev polynomial function



- Signal: Double Gaussian

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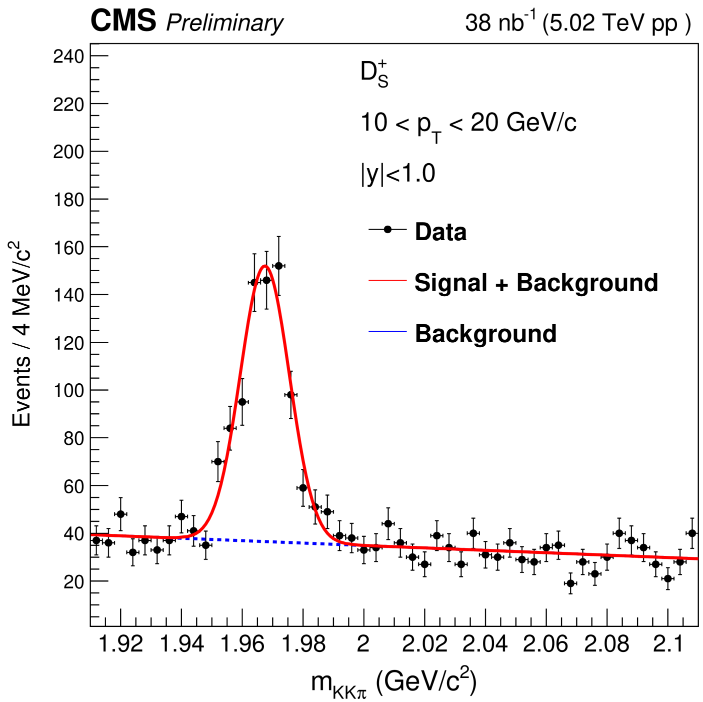
Signal Extraction D_s^+

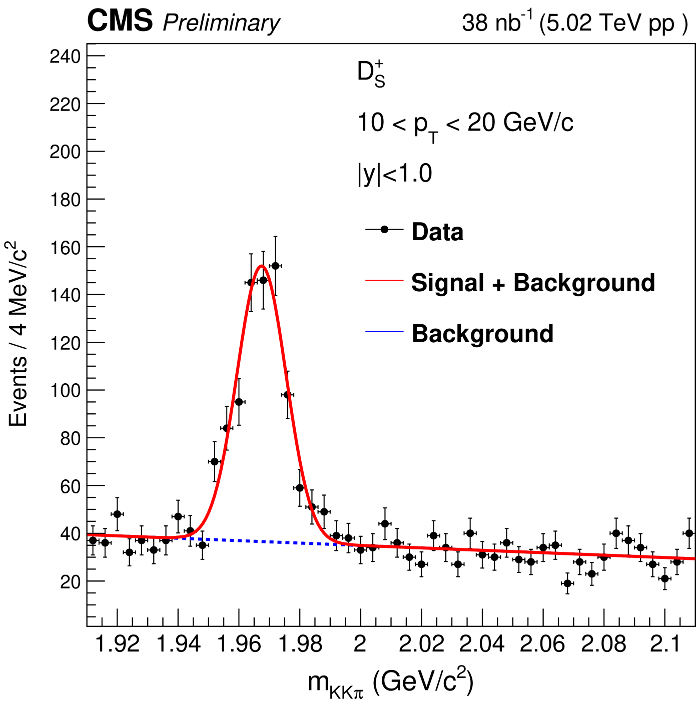


D_s^+

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

CMS-PAS-HIN-18-017

Signal Extraction D_s^+



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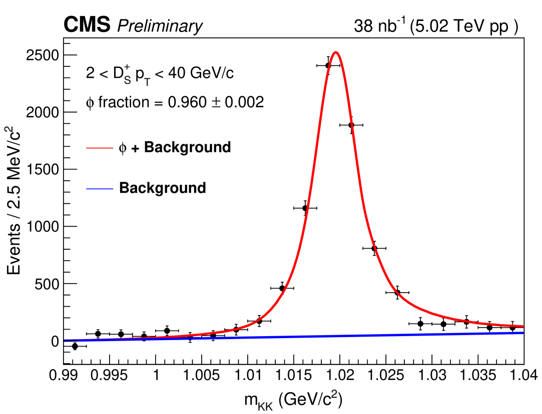
D_s^+



- K^+K^- mass fit:
  - Signal: $D_s^+ \to \varphi\pi^+ \to K^+K^-\pi^+$
  - Background: $D_s^+ \to f_0\pi^+ \to K^+K^-\pi^+$
    $D_s^+ \to K^+\overline{K}^{*0} \to K^+K^-\pi^+$

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Results: p_T spectra

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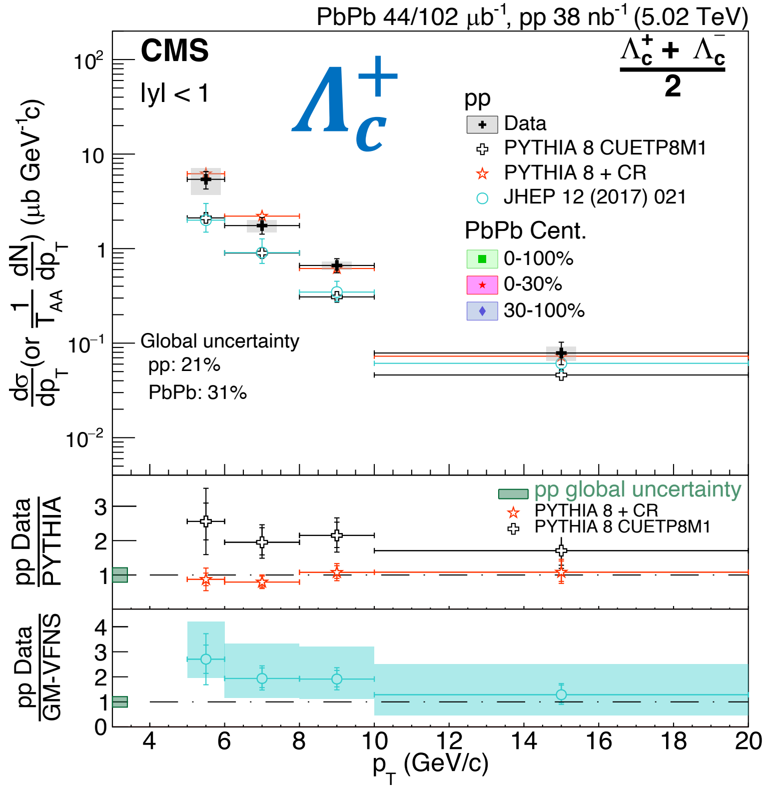

- PYTHIA 8 systematically below data
- PYTHIA 8 + CR consistent with pp data
- GM-VFNS Systematically below data for p_T < 10 GeV/c

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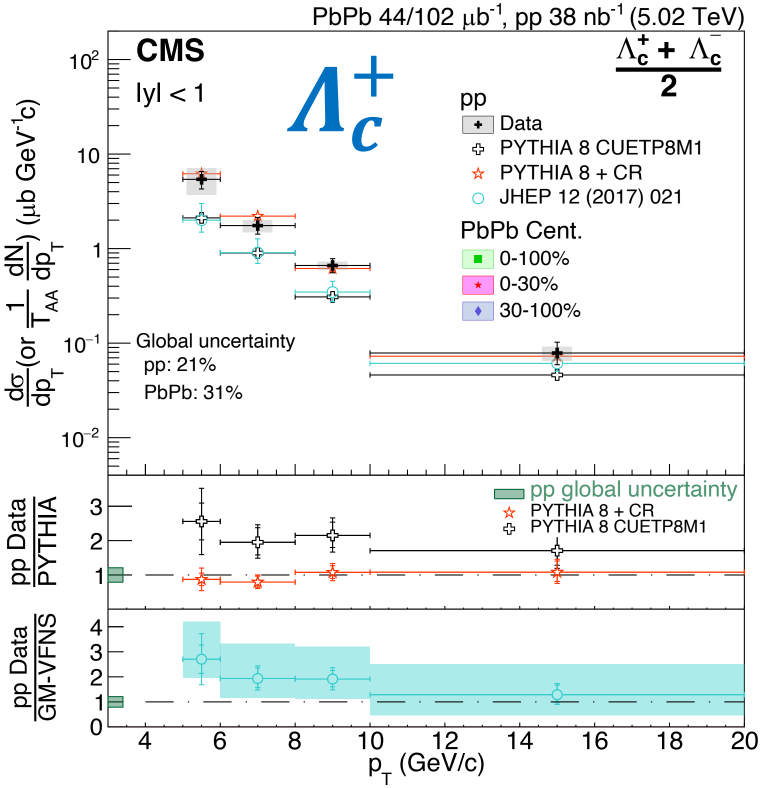

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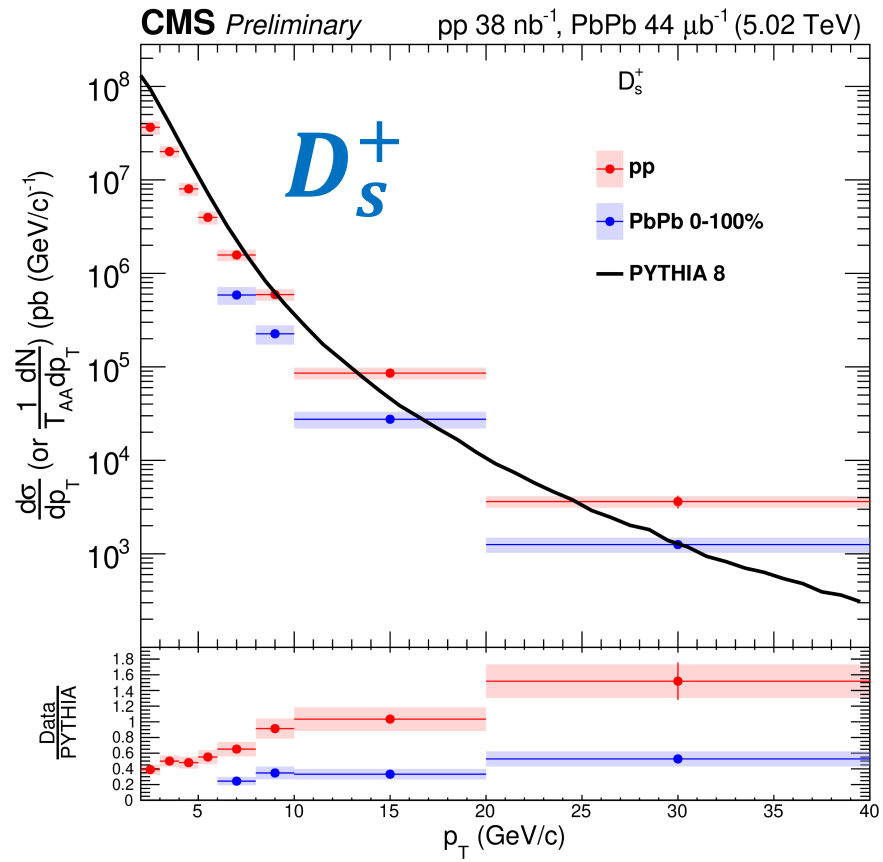

- PYTHIA 8 overestimates data at low p_T
- At higher p_T prediction below data

Results: R_{AA}

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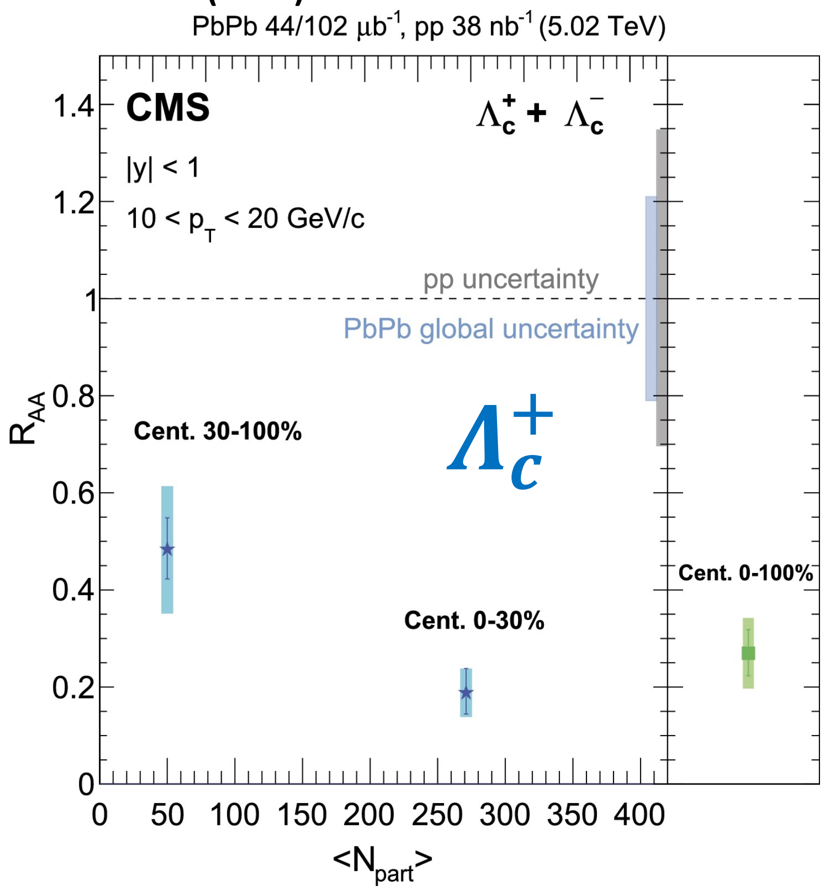

- Indication of Λ_c^+ suppression in PbPb collision
- Suppression larger in central events

Results: R_{AA}

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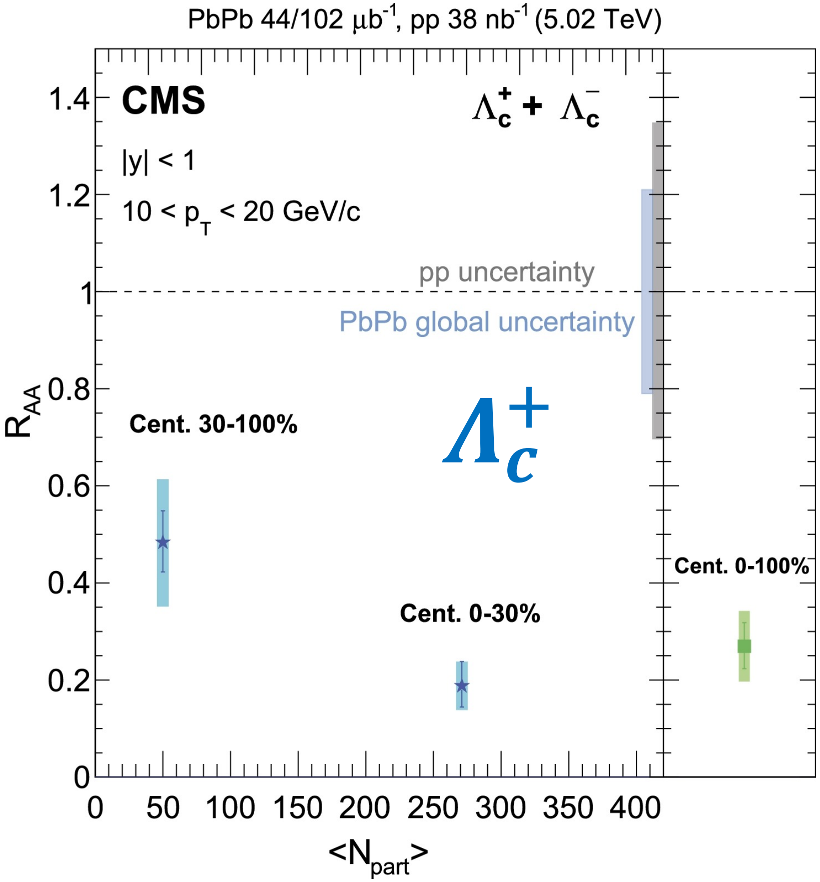

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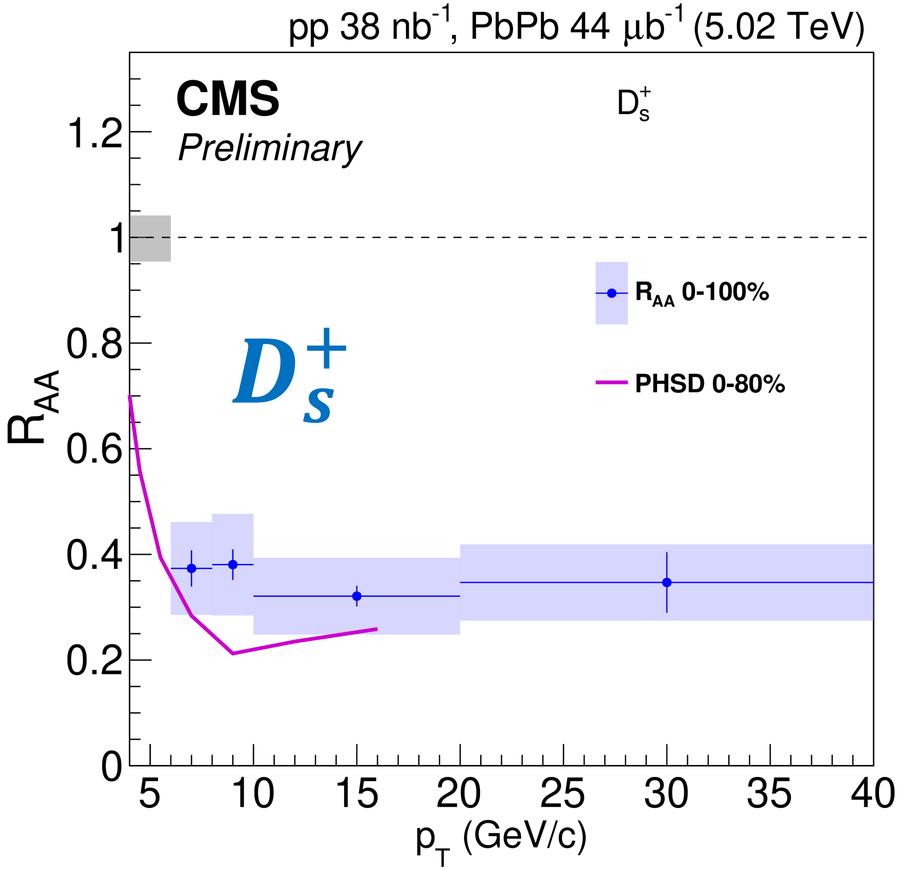

- D_s suppressed in PbPb collision
- No significant p_T dependence observed
- PHSD systematically below data
  - PRC **93** (2016) 034906

Results: Λ_c/D_0

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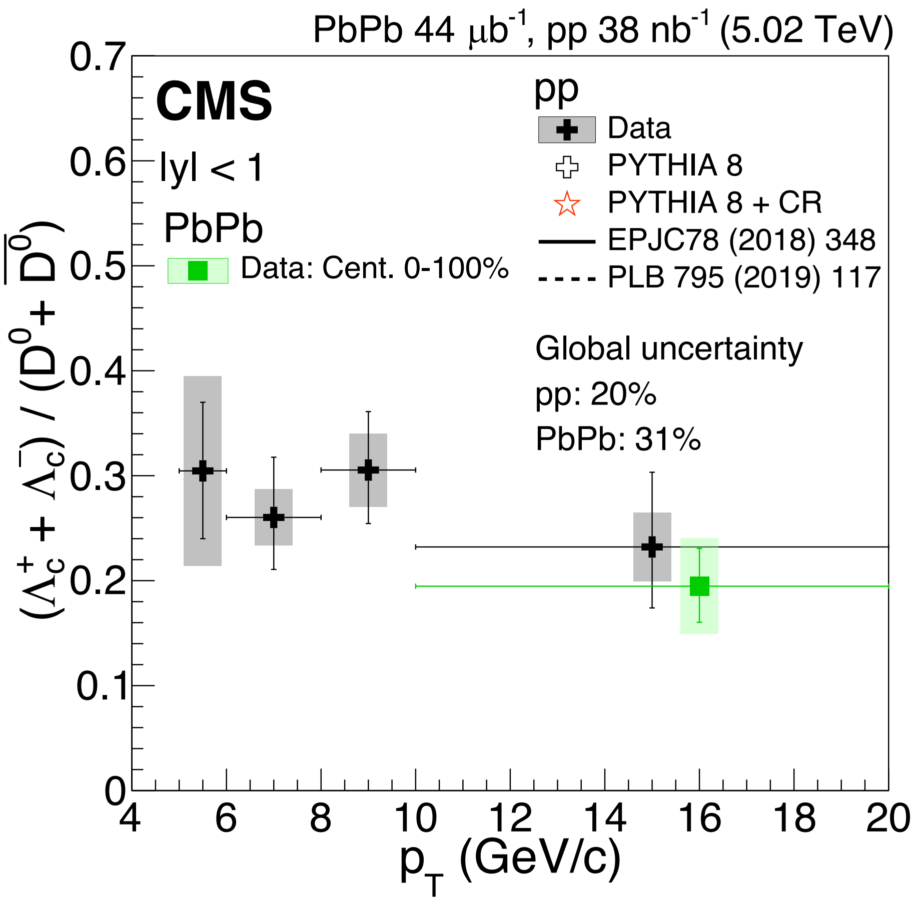

- **Similarity between pp & PbPb results suggest that there is no significant coalescence of Λ_c^+ (10 < p_T < 20 GeV/c)**
- No significant p_T dependence observed

Results: Λ_c/D_0

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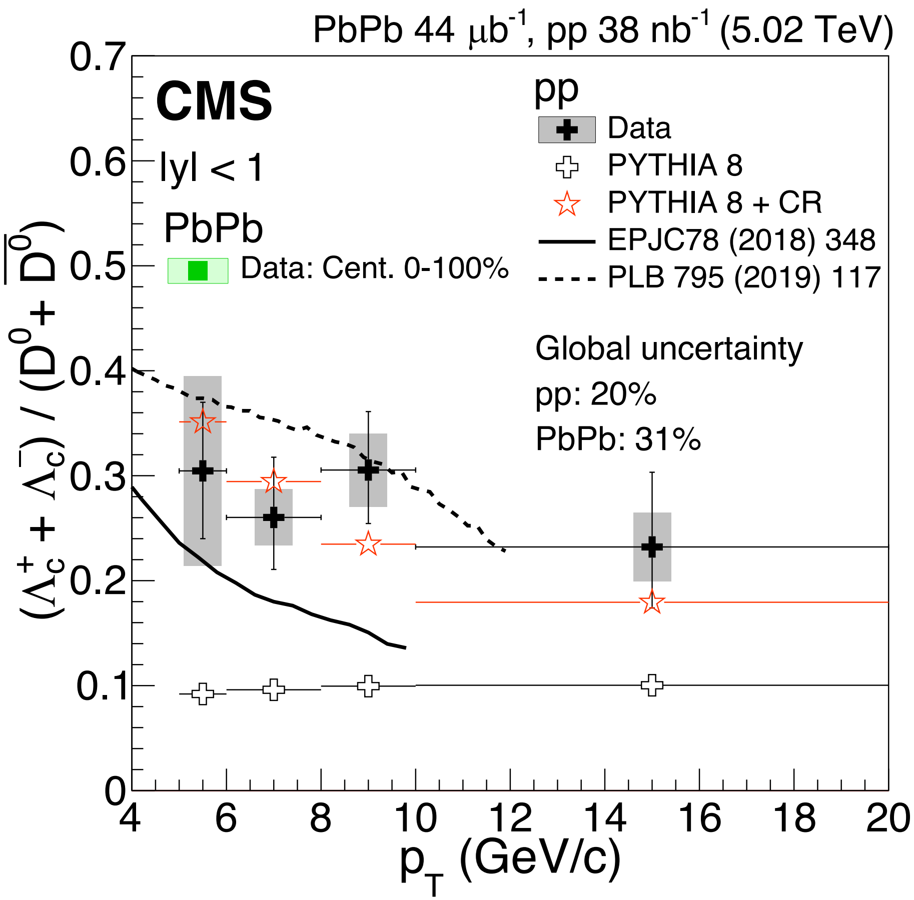
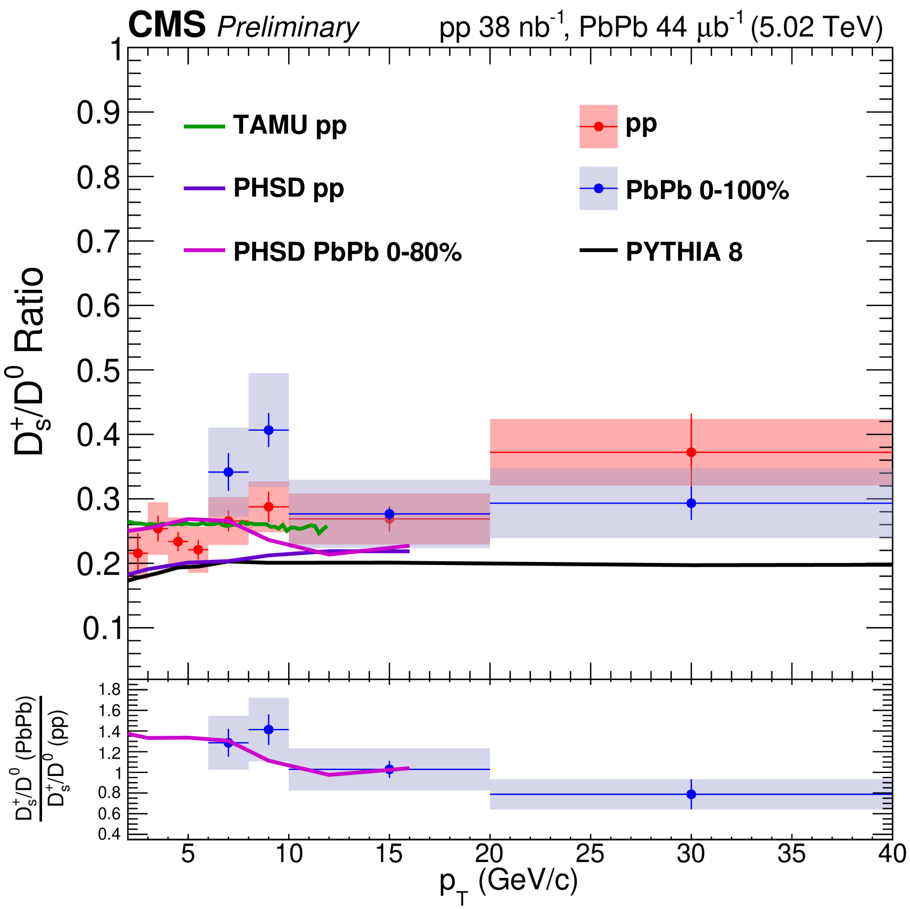


- **Similarity between pp & PbPb results suggest that there is no significant coalescence of Λ_c^+ (10 < p_T < 20 GeV/c)**
- No significant p_T dependence observed
- PYTHIA8 underestimates pp data
- PYTHIA8 + color reconnection – good description of data
- Solid line (Catania) - predicts stronger pT 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

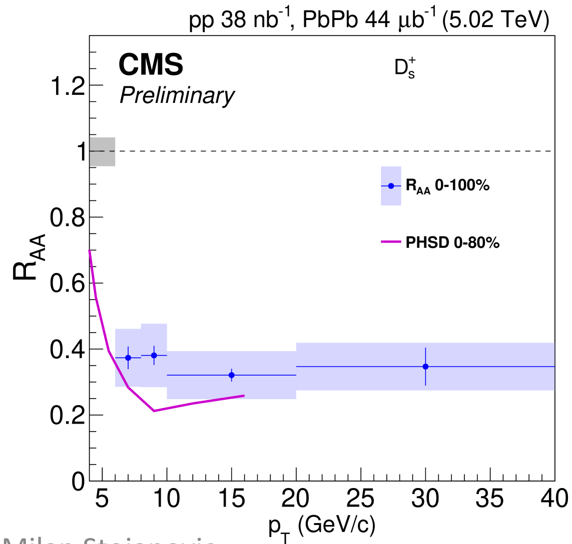
CMS-PAS-HIN-18-017

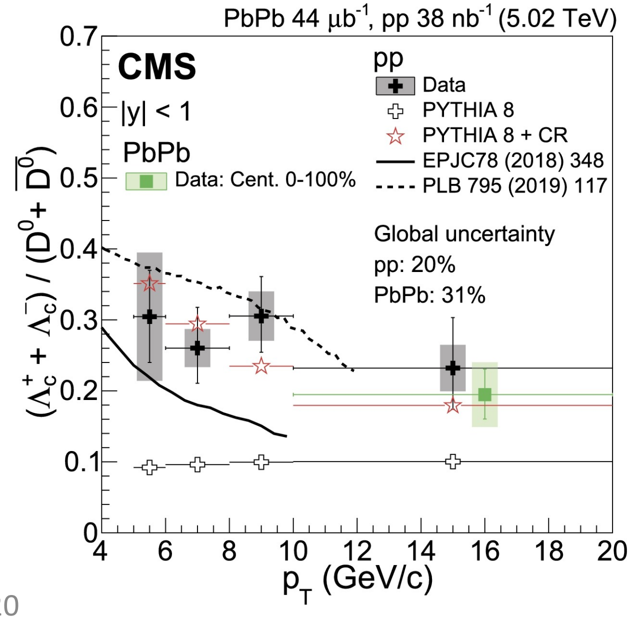


- Ratio similar for PbPb and pp collisions
- No significant p_T dependence observed
- PYTHIA8 shape consistent with pp data
- PHSD systematically below pp&PbPb data, but gives a good description of double ratio (PbPb/pp)
  - Microscopic transport model w only collision energy loss
  - PRC **93** (2016)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

Summary

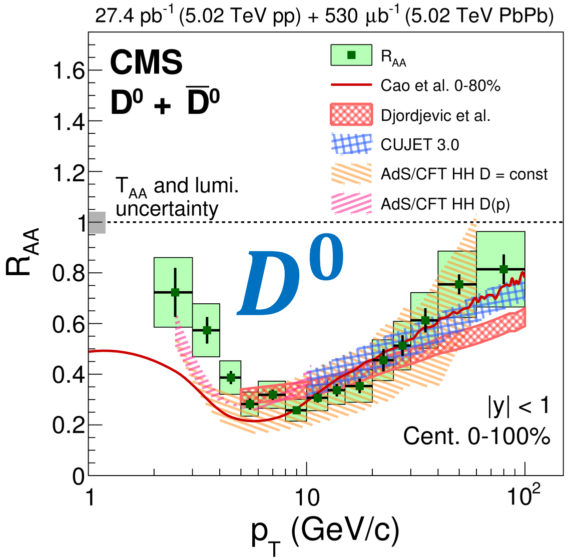
- Production of Λ_c^+ and D_s^+ measured in pp & PbPb collisions
- Suppression of Λ_c^+& D_s^+ consistent with D^0 results in PbPb
- No significant coalescence of Λ_c^+ observed for 10 < p_T < 20 GeV/c
- Λ_c^+ in pp described well by PYTHIA 8 + CR
- TAMU describes D_s^+/D^0 ratio well in pp; $\frac{D_s^+/D^0(PbPb)}{D_s^+/D^0(pp)}$ 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

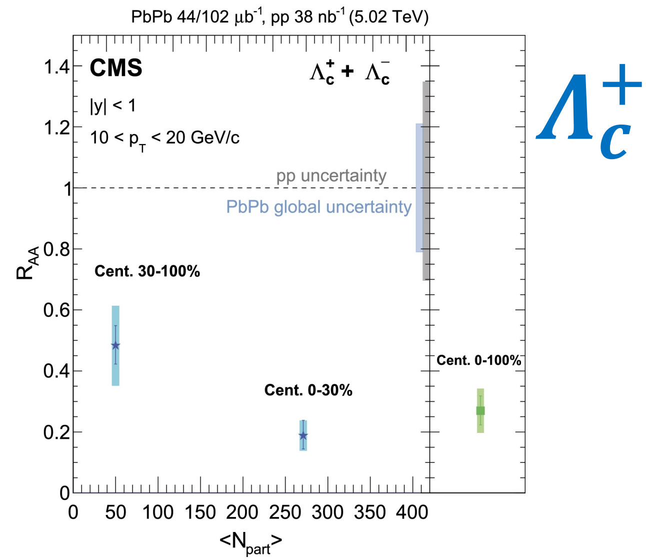


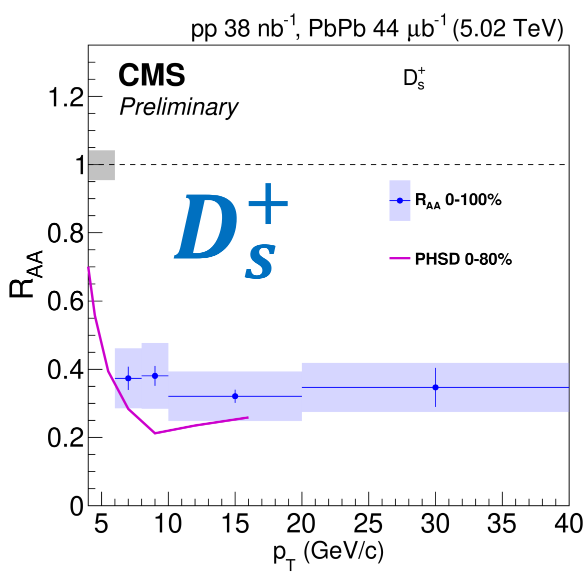


Backup Slides

R_{AA}

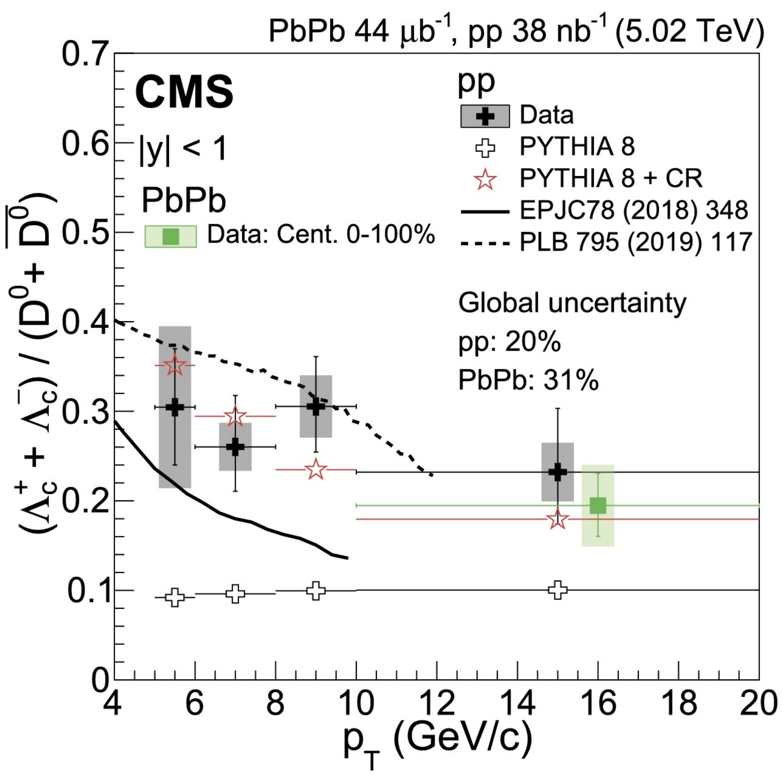

27.4 pb⁻¹ (5.02 TeV pp) + 530 μb⁻¹ (5.02 TeV PbPb)
CMS
D⁰ + D̄⁰
R_AA
Cao et al. 0-80%
Djordjevic et al.
CUJET 3.0
AdS/CFT HH D = const
AdS/CFT HH D(p)
T_AA and lumi. uncertainty
D⁰
|y| < 1
Cent. 0-100%
R_AA
p_T (GeV/c)


PbPb 44/102 μb⁻¹, pp 38 nb⁻¹ (5.02 TeV)
CMS
Λc⁺ + Λc⁻
|y| < 1
10 < p_T < 20 GeV/c
pp uncertainty
PbPb global uncertainty
Cent. 30-100%
Cent. 0-30%
Cent. 0-100%
R_AA
<N_part>
Λc⁺

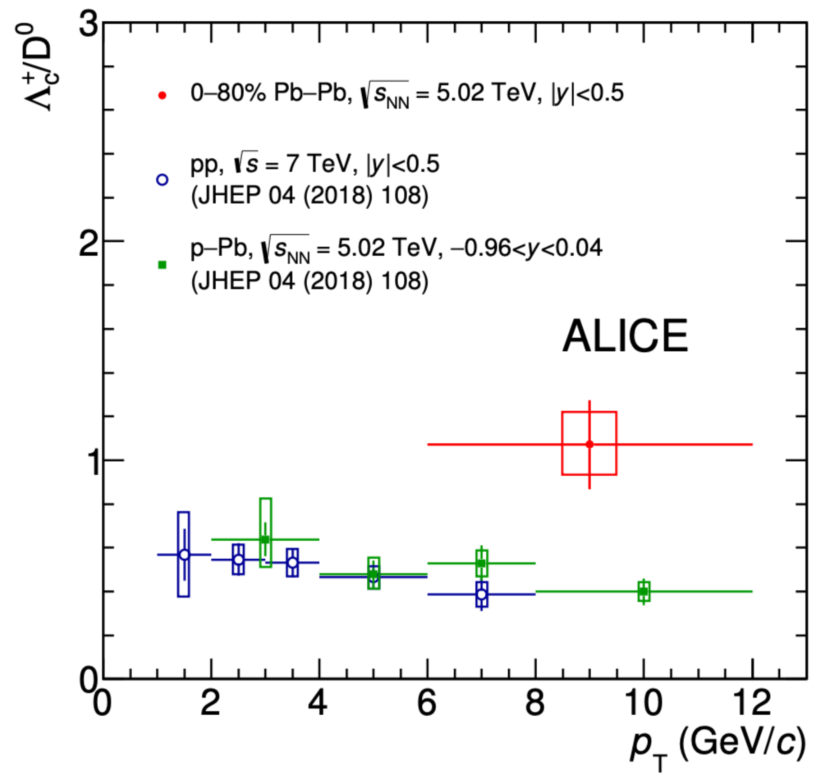

pp 38 nb⁻¹, PbPb 44 μb⁻¹ (5.02 TeV)
CMS
Preliminary
Ds⁺
R_AA 0-100%
PHSD 0-80%
R_AA
p_T (GeV/c)

Λ_c/D_0

CMS



ALICE



Λ_c uncertainty from nonprompt component

- 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 $\frac{R_{AA}^{nonprompt}}{R_{AA}^{prompt}}$ correction.)

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

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