Non-strange and strange D-meson and charm-baryon production in heavy-ion collisions measured with ALICE at the LHC

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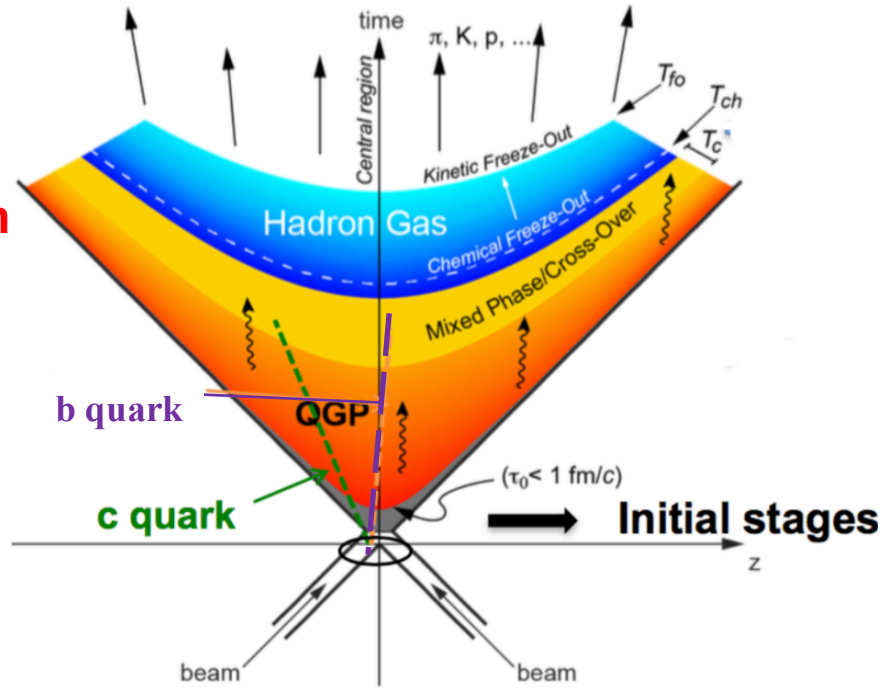
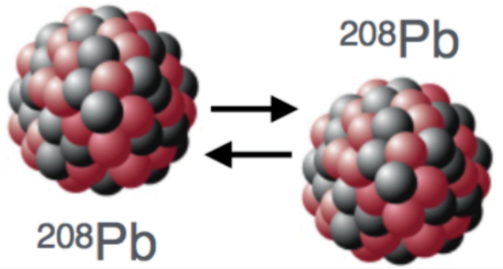
Heavy Flavour: effective probes of the QGP

- Produced in **initial hard scattering (high Q^2)** processes
- $\tau_{c/b} \sim 0.01 - 0.1$ fm/c < QGP formation time (~0.1-1 fm/c)
  - Experience the whole system evolution **interacting with the medium** formed in Pb-Pb collisions

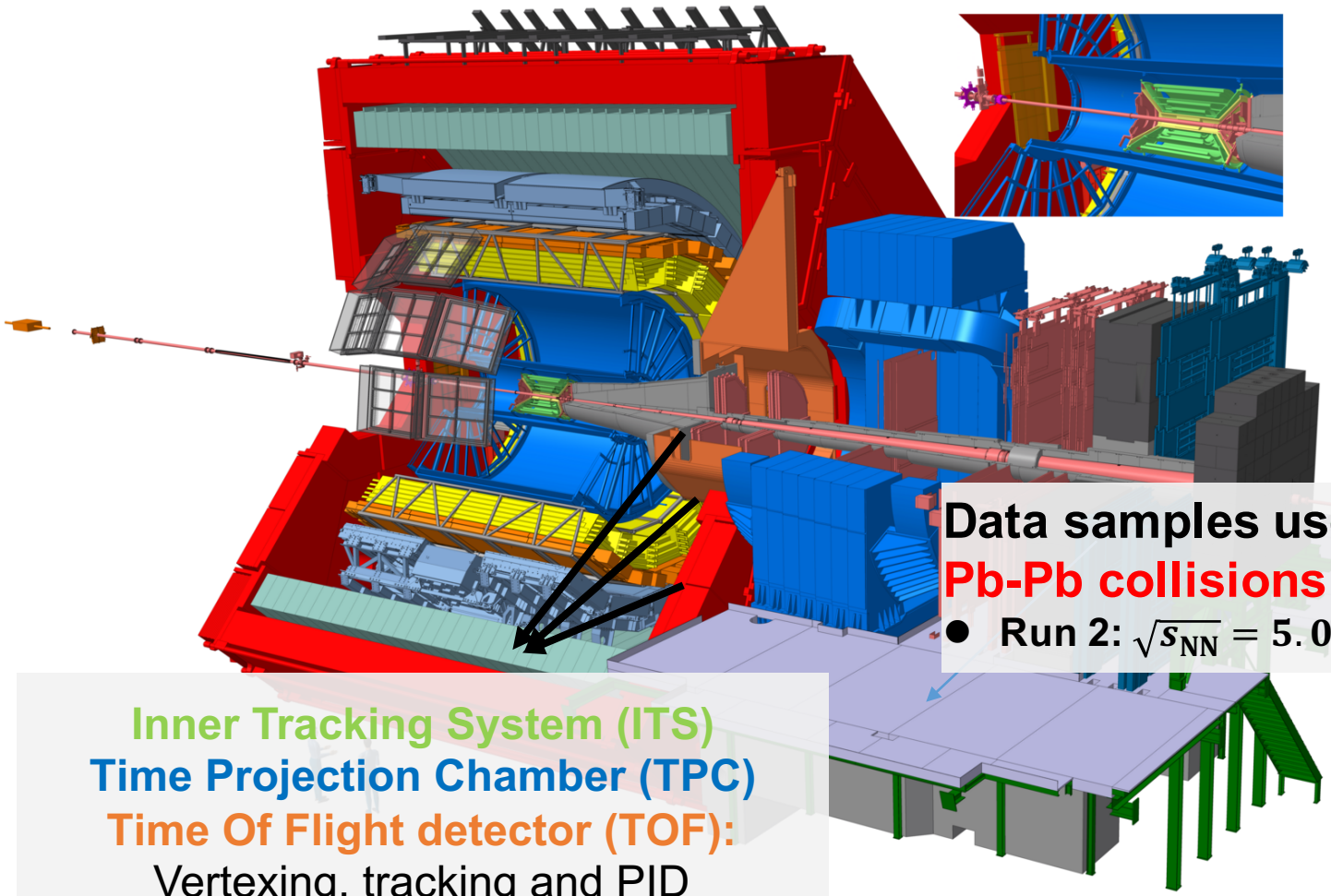


In Pb-Pb collisions:

- Study of charm energy-loss mechanism in the medium
  - Colour-charge and quark-mass dependence
- Participate in the collective motion and thermalisation of the medium
- Modification of hadronisation mechanism in the medium
  - **Coalescence mechanism**?
  - **Diquark in medium?**



The ALICE detector



V0, ZDC:
Event plane, trigger and centrality/multiplicity determination

Inner Tracking System (ITS)
Time Projection Chamber (TPC)
Time Of Flight detector (TOF):
Vertexing, tracking and PID
$|\eta| < 0.9$

Data samples used for the analyses discussed:

Pb-Pb collisions:

- **Run 2:** $\sqrt{s_{\mathrm{NN}}} = 5.02$ **TeV** : ~100*10^6 V0 min.bias events $L_{\mathrm{int}} = 13.4\ \mu\mathrm{b}^{-1}$

Hadronic decay channel reconstruction

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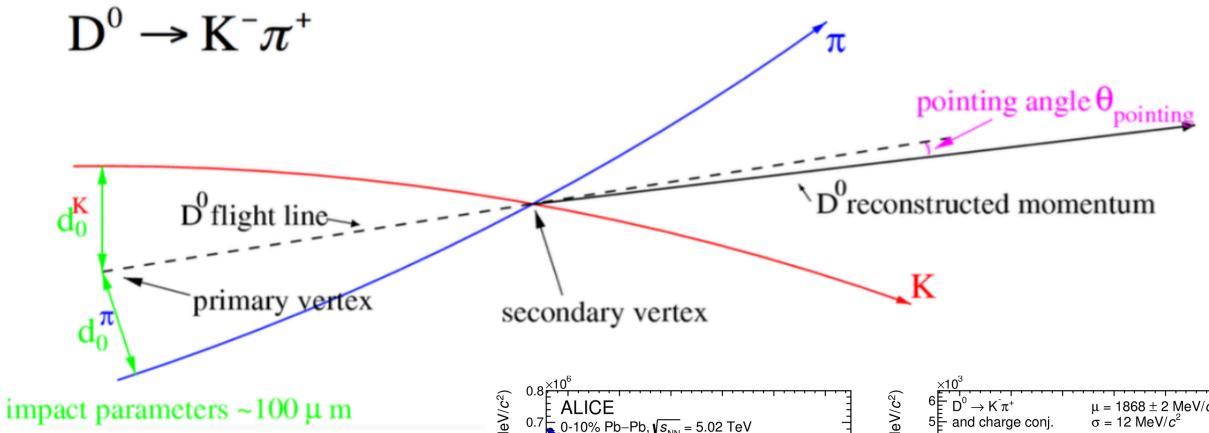
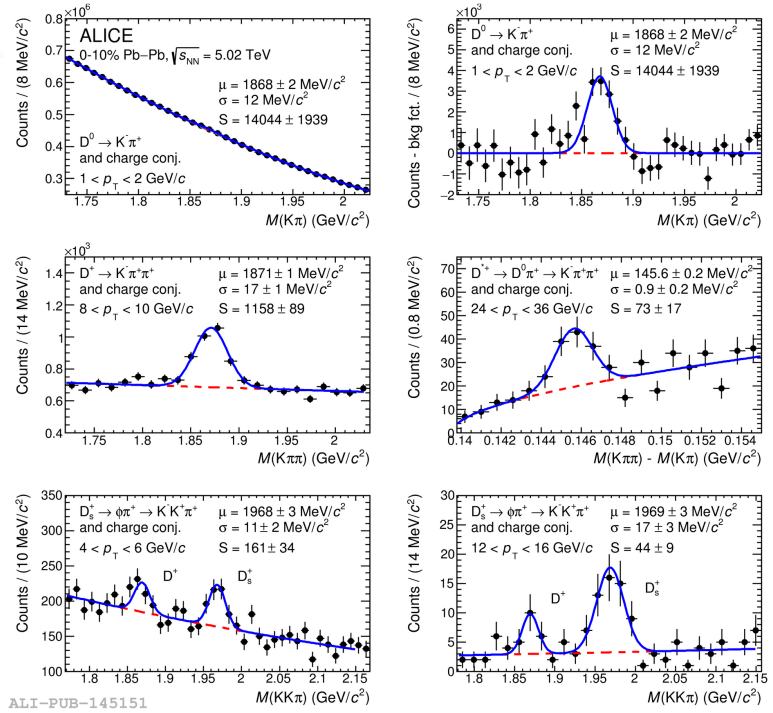
$D^0 \to K^-\pi^+$	BR ~ 3.93%	$c\tau \sim 123\ \mu m$
$D^+ \to K^-\pi^+\pi^+$	BR ~ 9.46%	$c\tau \sim 312\ \mu m$
$D^{*+} \to D^0(K^-\pi^+)\pi^+$	BR ~ 2.66%	-
$D_s^+ \to \phi(K^-K^+)\pi^+$	BR ~ 2.27%	$c\tau \sim 150\ \mu m$
$\Lambda_c^+ \to pK_s^0$	BR ~ 1.58%	"

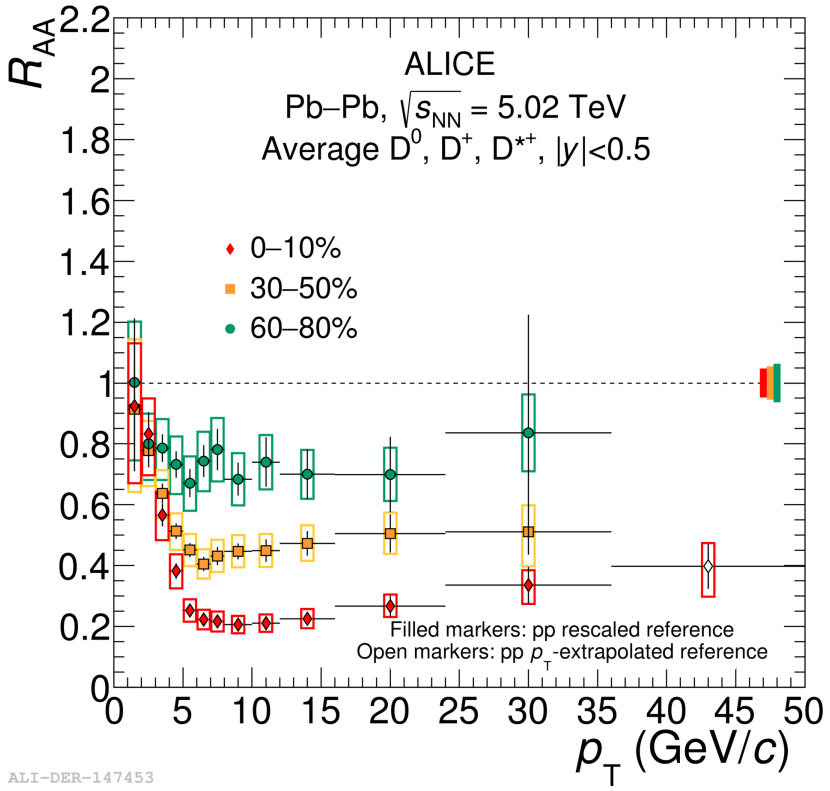




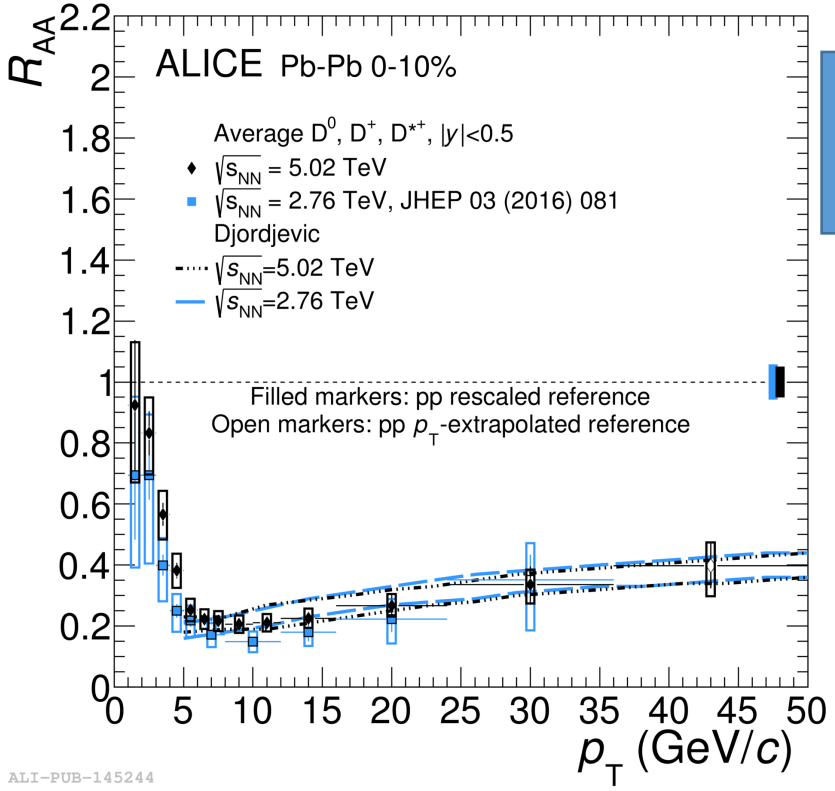
- Decay topology selections and PID used to reduce the combinatorial background
- Signal is extracted via an invariant-mass analysis
- Feed-down from beauty-hadron decays are subtracted exploiting FONLL calculations with assumptions on feed-down nuclear modification factor

[1] Djordjevic, Phys. Rev. C92 (2015) 024918

D meson R_{AA} in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV



60-80%
30-50%
0-10%



Improved precision in Run-2 with respect to Run-1 measurements

Published!

0-10%

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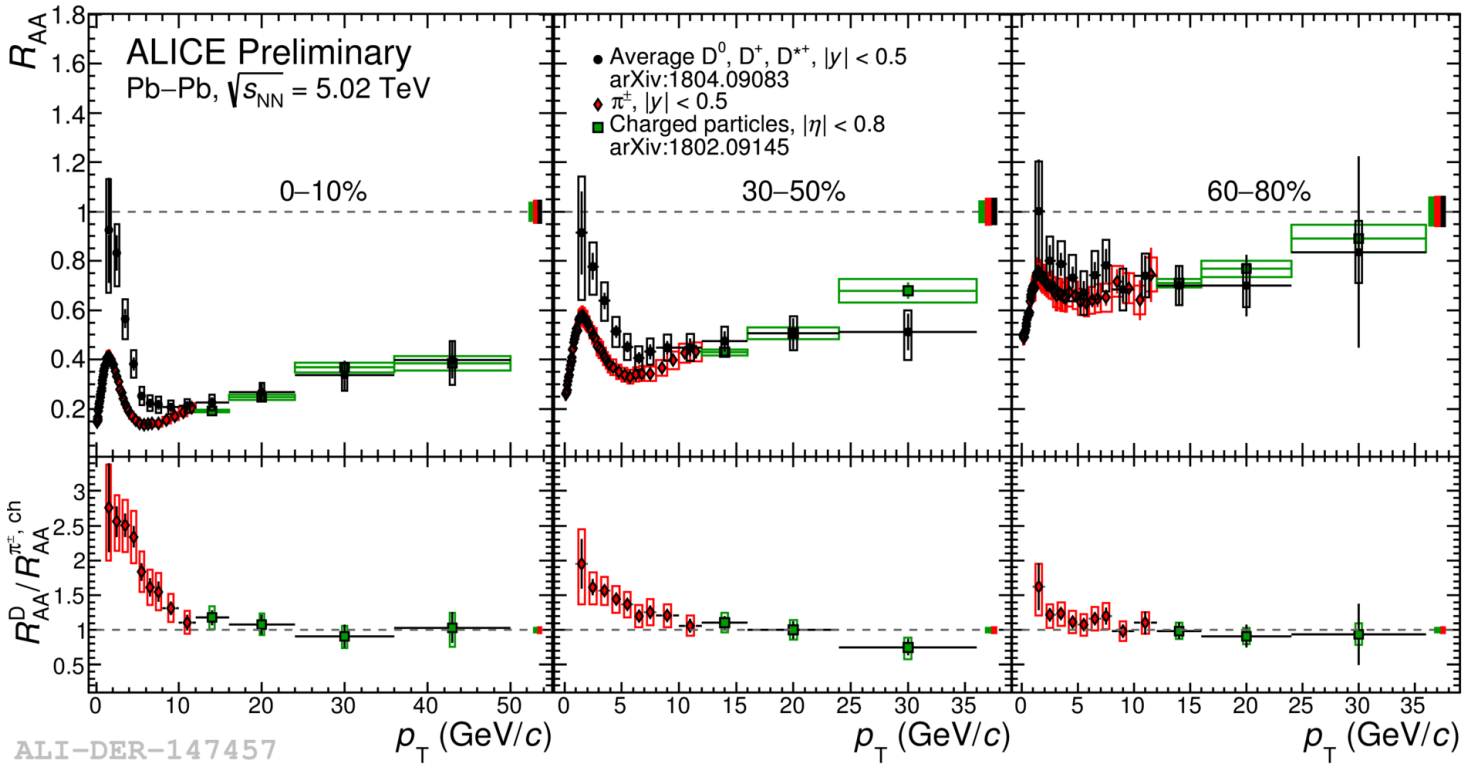
- **Strong suppression** of non-strange D meson in Pb-Pb at $\sqrt{s_{NN}} = 5.02$ TeV, increasing with centrality
- Similar suppression between $\sqrt{s_{NN}} = 2.76$ TeV and $\sqrt{s_{NN}} = 5.02$ TeV
  - ➢ Described by model [1] at two energies -> **harder spectra and denser medium counterbalance**

D-meson and charged-particle R_{AA} comparison



Published!

$\pi^{\pm}$ ALICE preliminary

Charged-particle: arXiv:1802.09145

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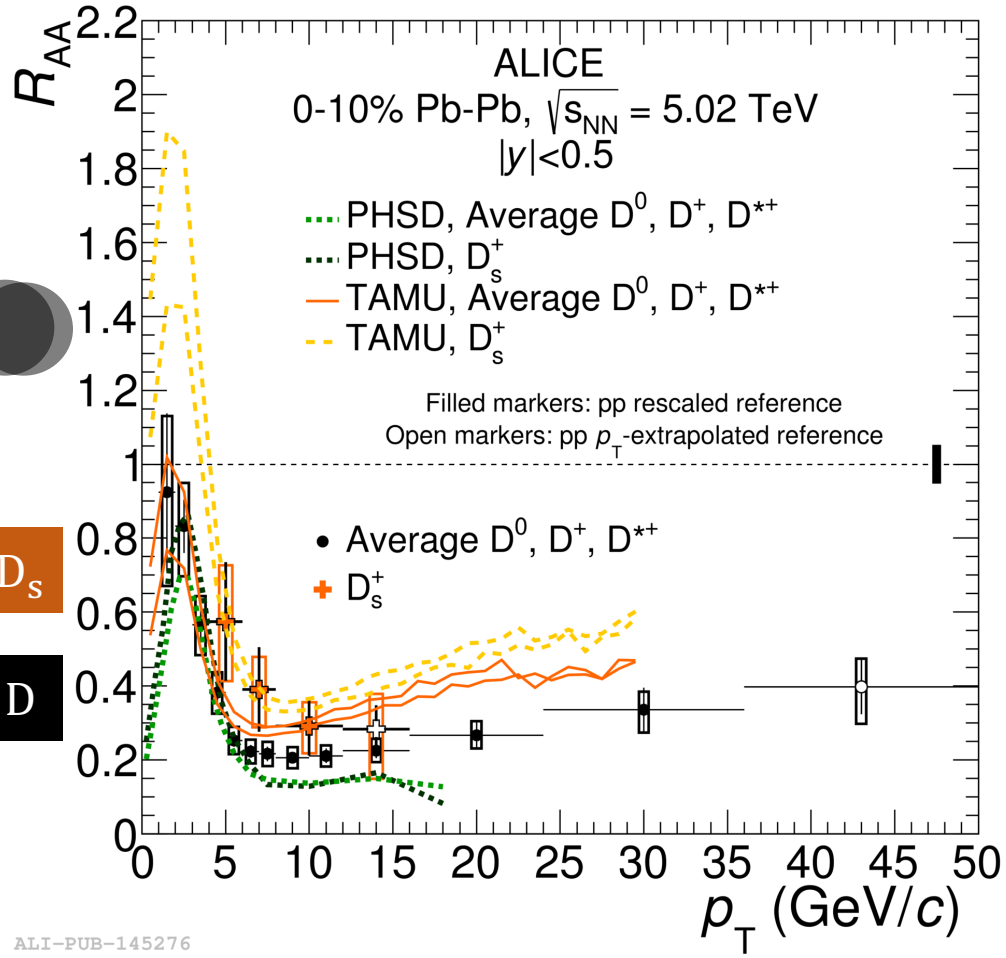
- Similar D-meson, $\pi^{\pm}$ and charged-particle R_{AA} result for $p_T > 10$ GeV/c in 0-10% and 30-50%, compatible results in 60-80% for $p_T > 1$ GeV/c
- D-meson R_{AA} larger than that of charged pions at low p_T for 0-10% and 30-50% centrality classes
  - Not straightforward interpretation: N_{part} vs N_{coll} scaling at low p_T, different fragmentation and initial spectra shapes, possible mass and Casimir factor effects, different impact of coalescence and radial flow

strange and non-strange D-meson R_{AA}

PHSD: Phys. Rev. C93 no. 3, (2016) 034906
TAMU: Phys.Lett. B735 (2014) 445–450
Catania: Eur.Phys.J.C (2018) 78:348



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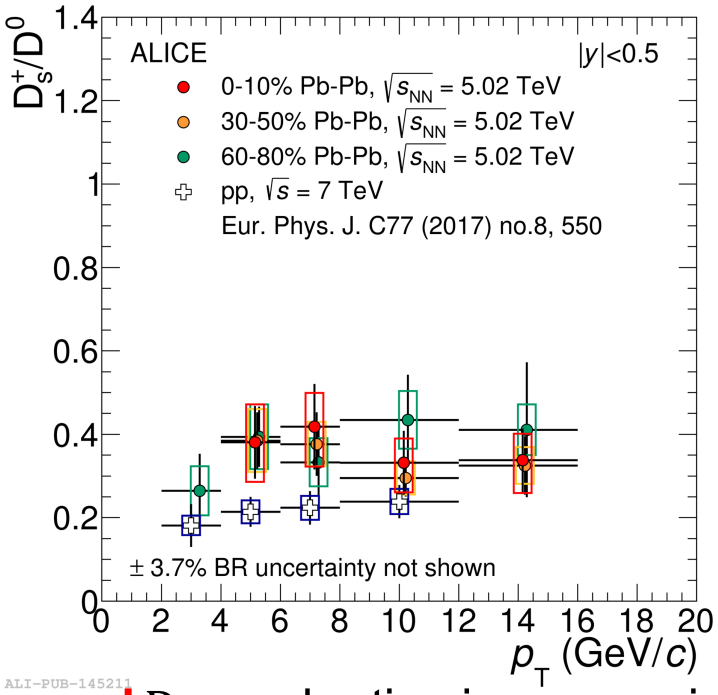

Published!

- Hint of **enhanced** D_s production in comparison to non-strange D mesons in Pb-Pb collisions. Expected from models
  - **Effect of coalescence + strangeness enhancement?**

strange and non-strange D-meson R_{AA}

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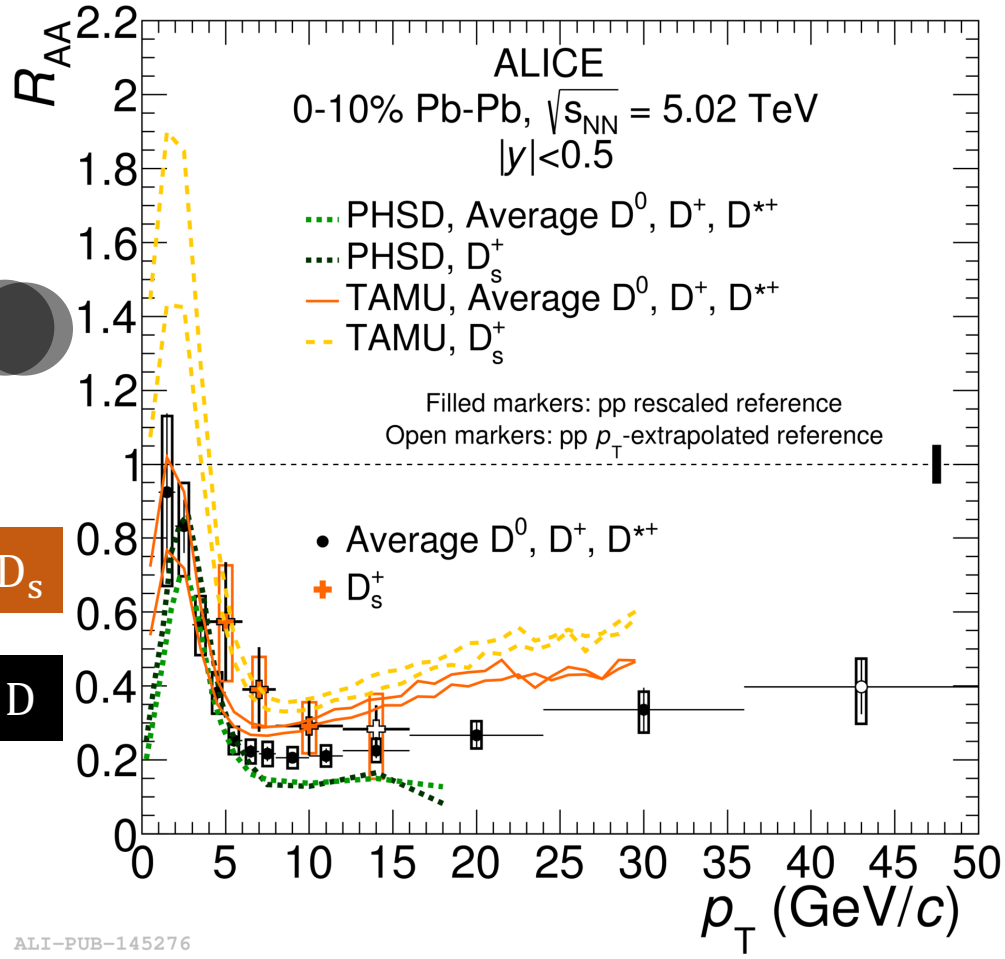

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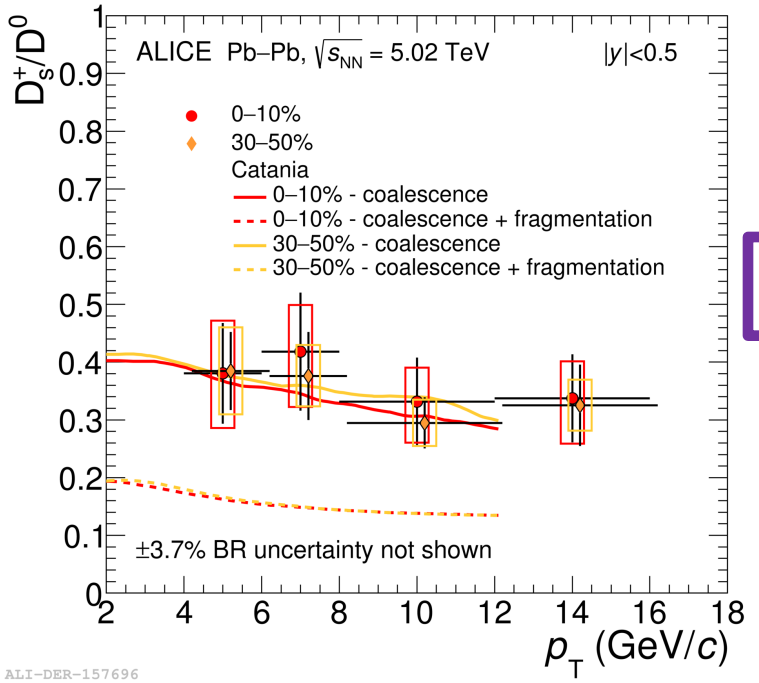
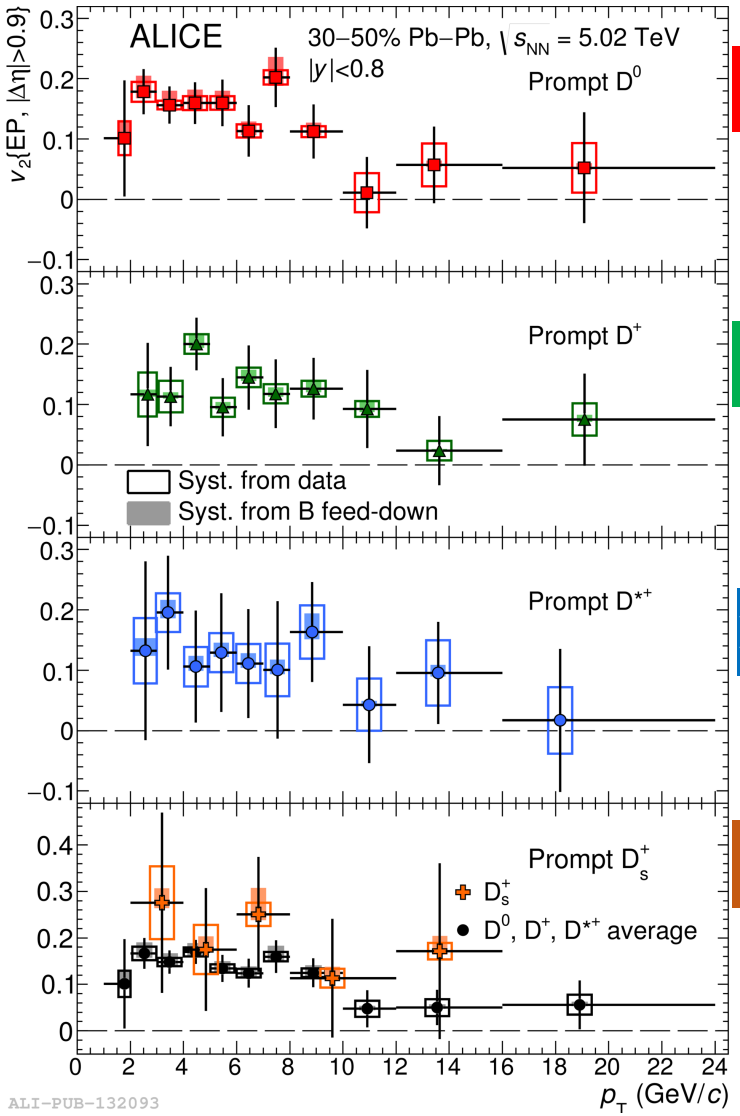


Published!

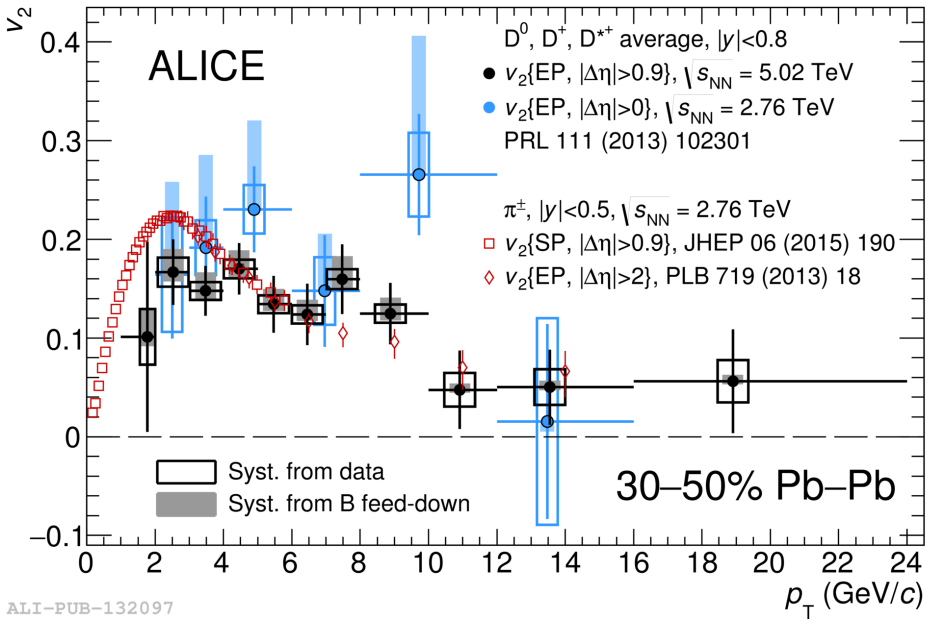
- Hint of **enhanced** D_s production in comparison to non-strange D mesons in Pb-Pb collisions. Expected from models
  - **Effect of coalescence + strangeness enhancement?**
- D_s/D^0: no evidence for centrality dependence within uncertainties
  - Negligible centrality-dependence expected by pure-coalescence scenario

D-meson v_2

Phys. Rev. Lett. 120 (2018) 102301



D⁰ D⁺ D*⁺ Dₛ



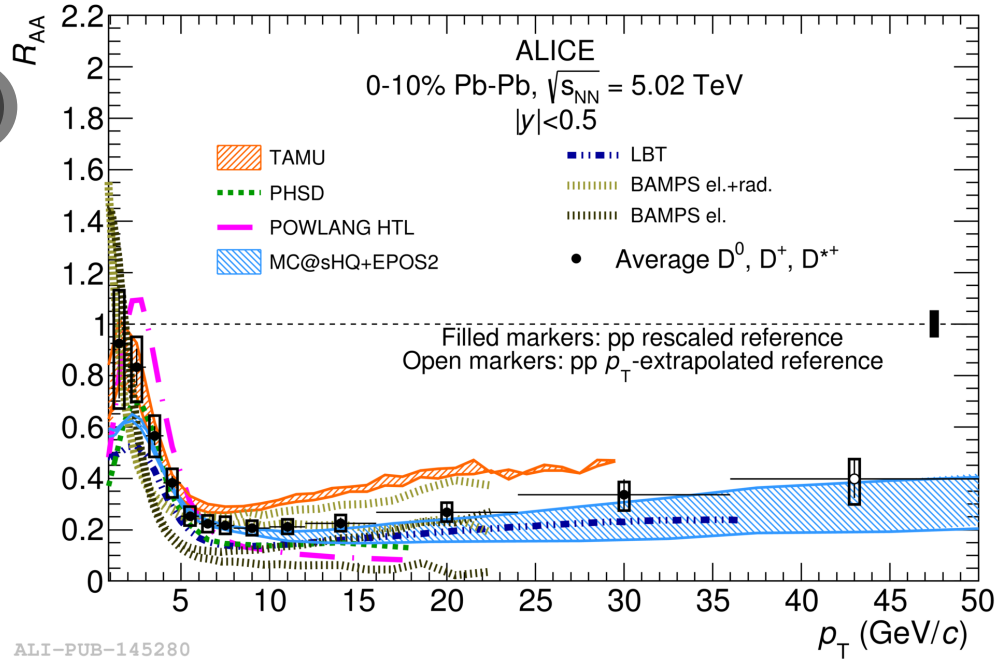
D Run 2
D Run 1
$\pi^{\pm}$

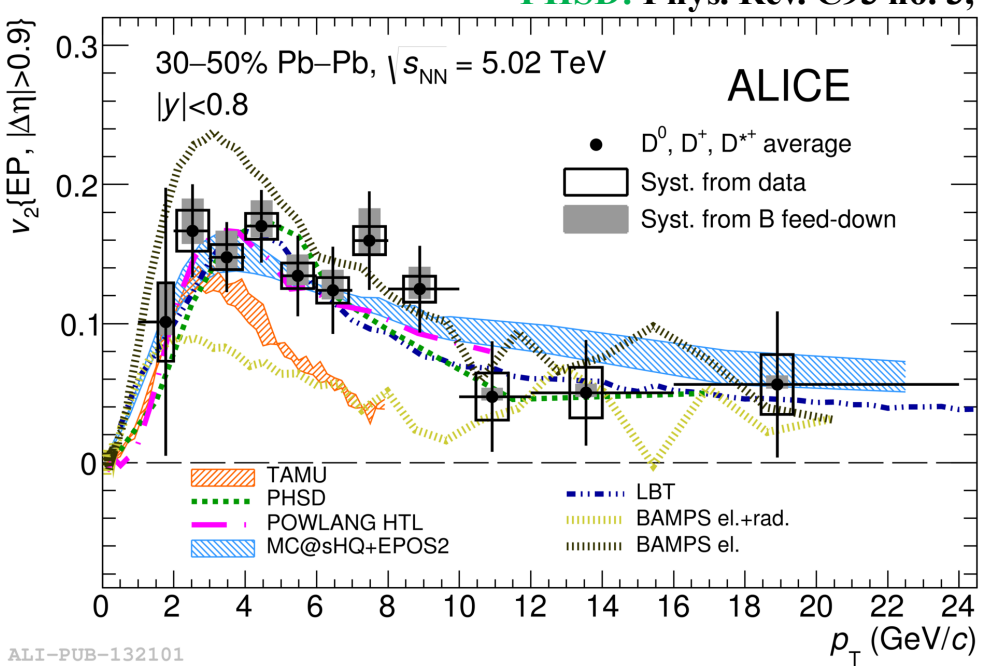
Published!

- **Positive** D-meson v_2 in $2 < p_T < 10$ GeV/c
  - Charm quark sensitive to medium collective motion
- **First** measurement of D_s^+ v_2
  - Compatible with that of non-strange D mesons
- D-meson v_2 compatible between $\sqrt{s_{NN}} = 2.76$ TeV and $\sqrt{s_{NN}} = 5.02$ TeV
- D-meson v_2 is similar to that of charged pions
  - Hint of **larger** pion v_2 at $p_T < 4$ GeV/c

Comparison with models

POWLANG: Eur. Phys. J. C75 no. 3, (2015) 121
MC@sHQ: Phys.Rev. C89 no. 1, (2014) 014905
LBT: Phys. Lett. B777 (2018) 255–259
BAMPS: J. Phys. G42 no. 11, (2015) 115106
PHSD: Phys. Rev. C93 no. 3, (2016) 034906





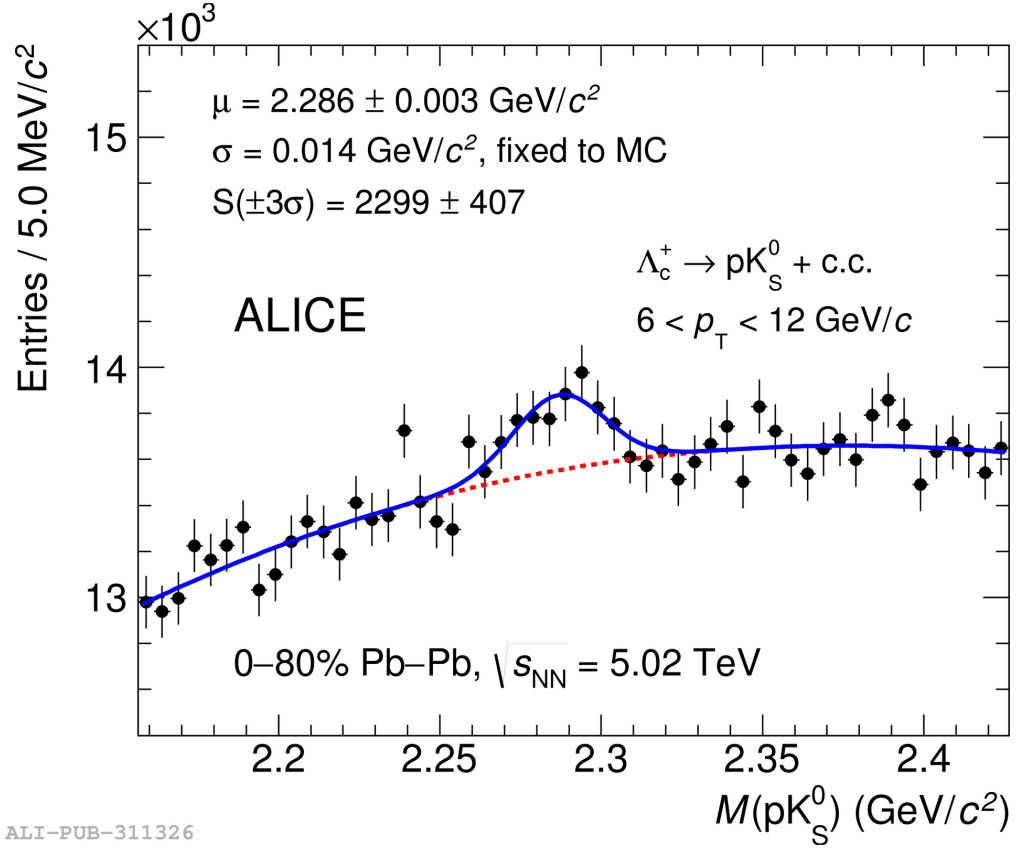
Published!

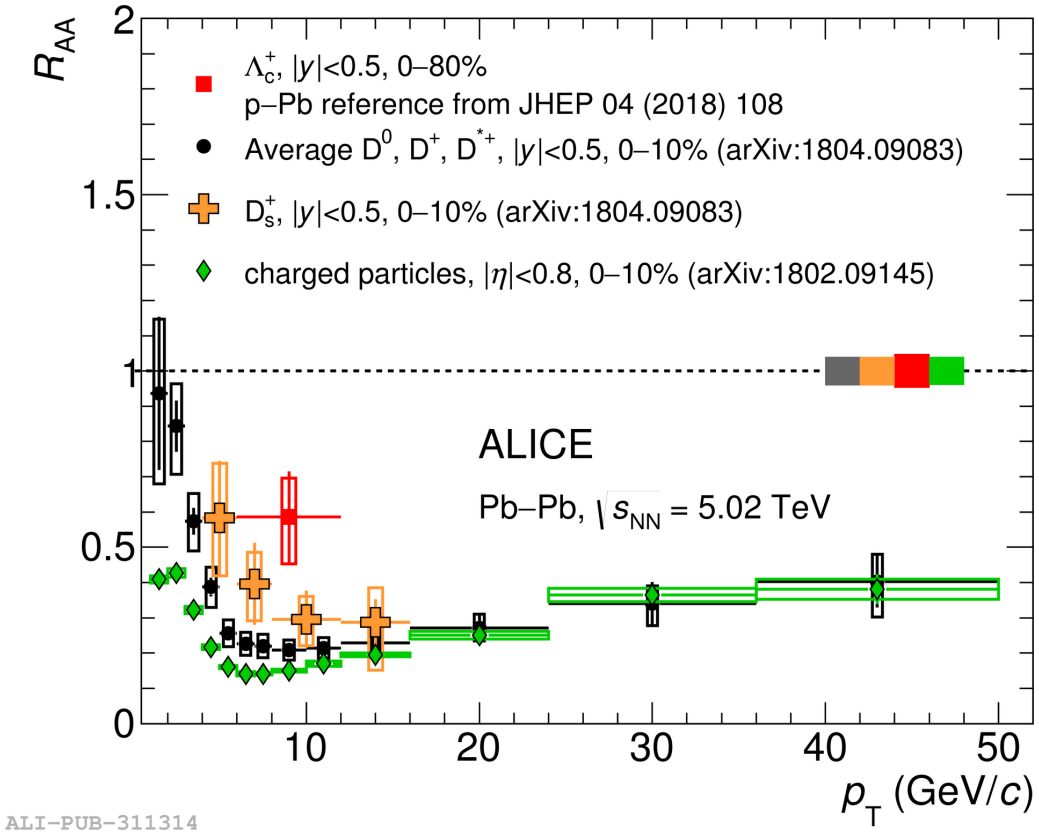
- Models in which charm quarks pick up collective flow via **recombination or subsequent elastic collisions in expanding medium** better describe both v_2 and R_{AA} at low p_T (**LBT**, **MC@sHQ**, **PHSD**, **POWLANG**)
- Improved precision of the measurement can provide **important constraints** on models and help to extract information about the medium properties. For models describing reasonably the data
  - v_2 -> Diffusion coefficient $1.5 < 2\pi T D_s(T) < 7$ at T_c -> Charm thermalisation time τ_{charm} = 3-14 fm/c

Λ_c^+ invariant mass and R_{AA} in Pb-Pb

$6 < p_T < 12$ GeV/c 0-80%

arXiv:1809.10922





- Hint of larger R_{AA} for Λ_c^+ at 0-80% than D meson at 0-10%
  - ➢ Hierarchy Λ_c^+ R_{AA} > D_s^+ R_{AA} > non-strange D-meson R_{AA} > pion R_{AA}

Λ_c^+ invariant mass and R_{AA} in Pb-Pb

$6 < p_T < 12$ GeV/c 0-80%

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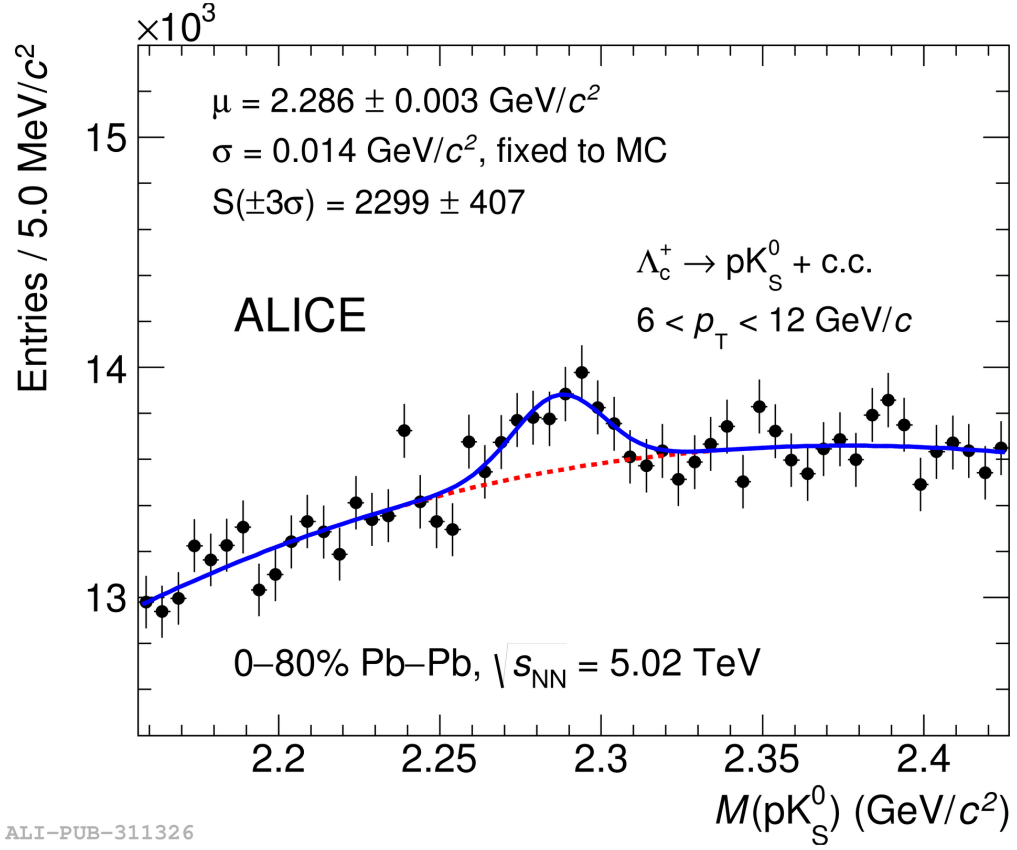
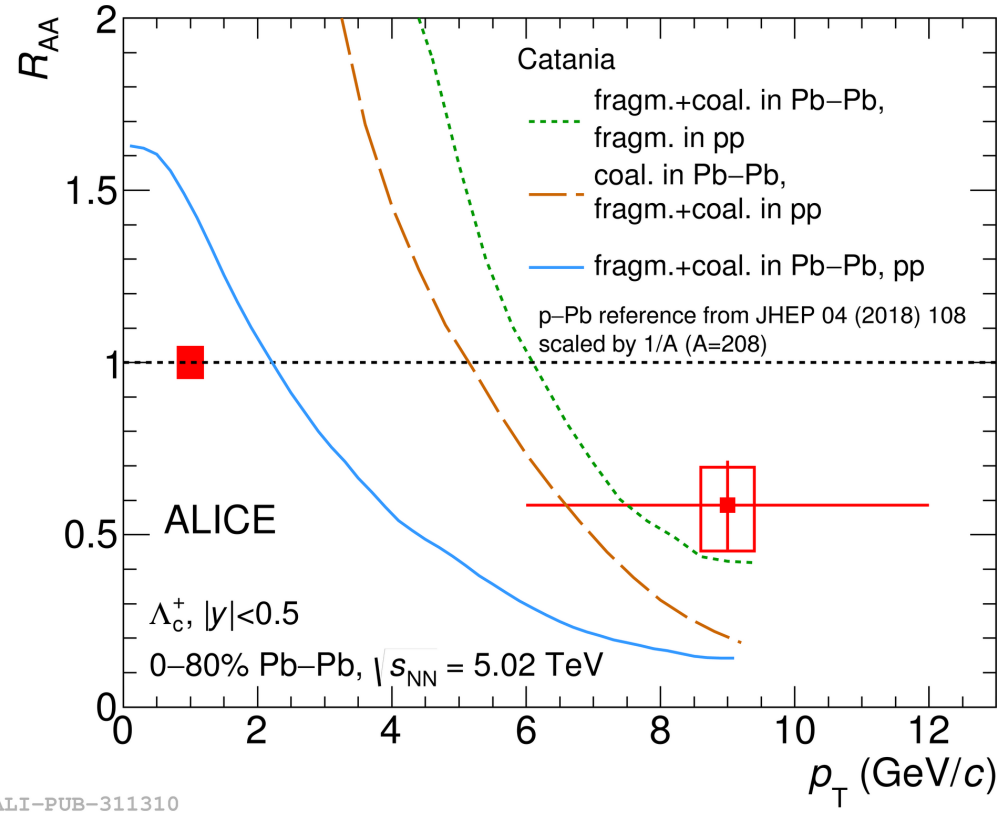
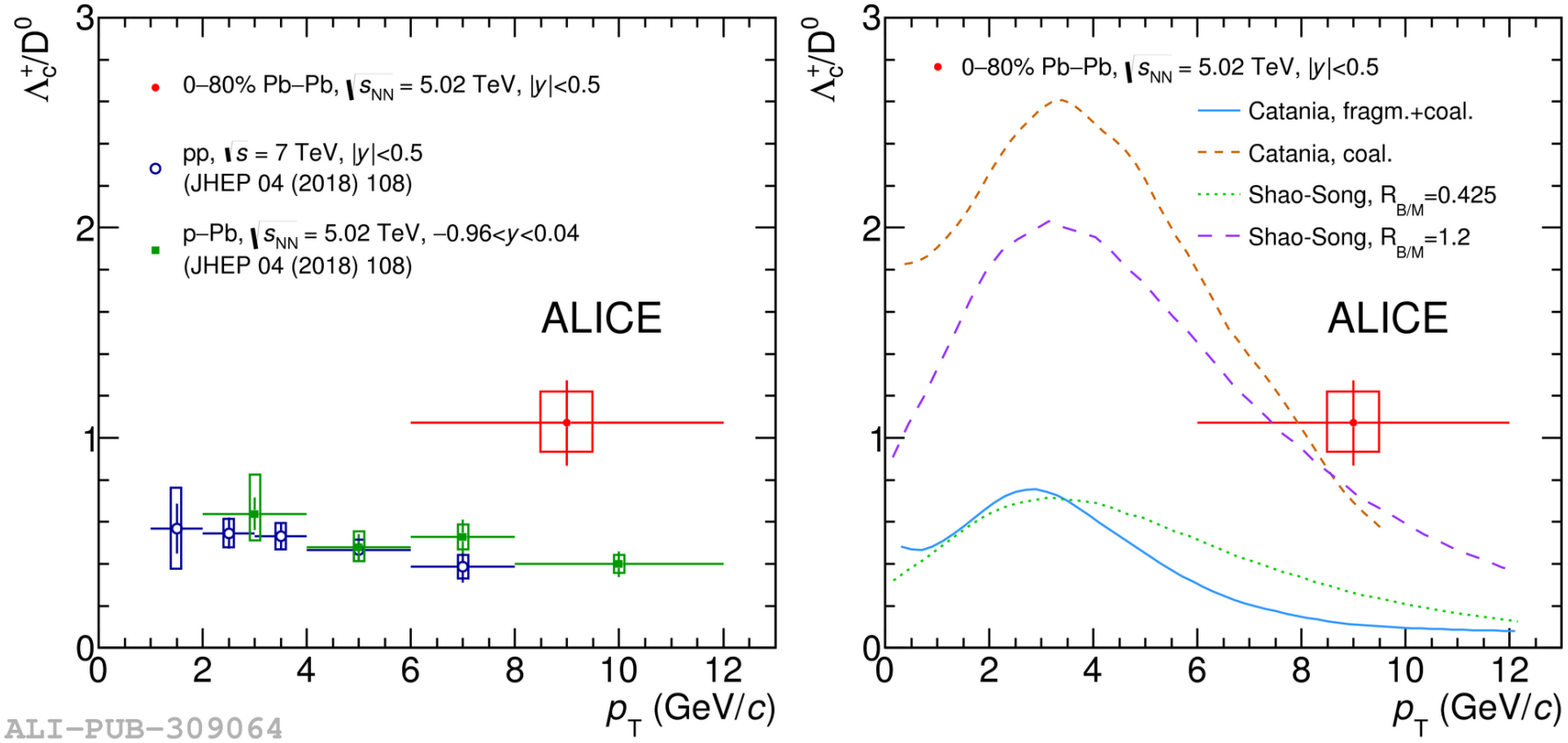




- Qualitatively in agreement with the scenario of fragmentation in pp and fragmentation+coalescence in Pb-Pb collisions

Catania: Eur.Phys.J.C (2018) 78:348

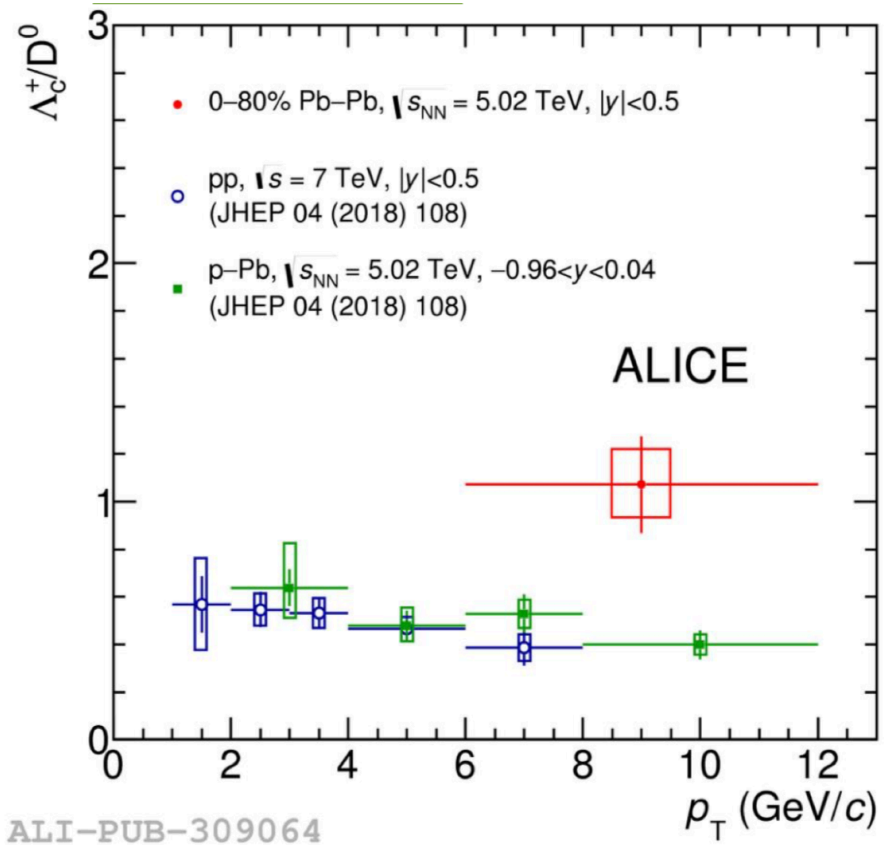
Λ_c^+/D^0 ratio in Pb-Pb

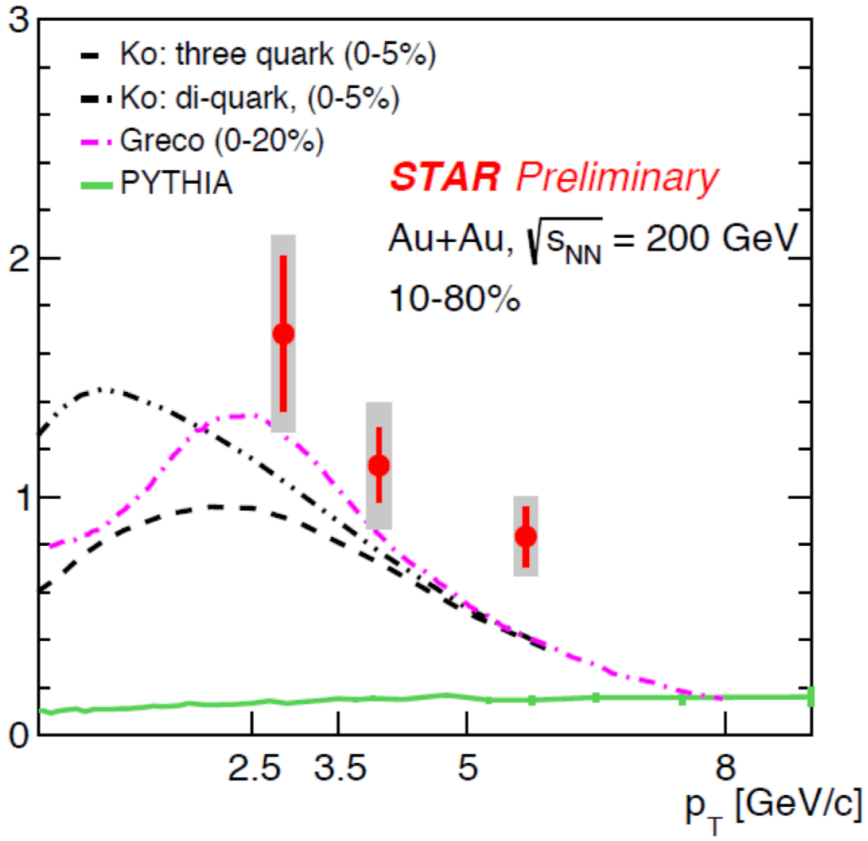


- Λ_c^+/D^0 ratio measured in Pb-Pb, hint of enhancement w.r.t pp and p-Pb
- Λ_c^+/D^0 results described by model calculations including only coalescence.

Shao-Song: Phys. Rev. C 97, 064915
Catania: Eur.Phys.J.C (2018) 78:348

Λ_c^+/D^0 ratio in Pb-Pb





- Λ_c^+/D^0 ratio measured in Pb-Pb, hint of enhancement w.r.t pp and p-Pb
- Λ_c^+/D^0 results described by **model calculations including only coalescence**.
- Λ_c^+/D^0 in $6 < p_T < 12$ GeV/c is similar to STAR measurement in 3-6 GeV/c.

Catania: Eur.Phys.J.C (2018) 78:348

Summary

- **New charmed-baryon measurements:**
  - **Λ_c^+/D^0 in Pb-Pb collisions, hint of enhancement w.r.t pp and p-Pb collisions**
- **D mesons results in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV :**
  - D^0, D^+, D^{*+}, D_s^+ R_{AA}: **increasing suppression** from peripheral to central collisions
  - Ratio of D_s^+ w.r.t non-strange D-meson results: **hint of enhancement in Pb-Pb w.r.t pp → coalescence and strangeness enhancement?**
  - D^0, D^+, D^{*+}, D_s^+ v_2 : **strong coupling of charm quark with the medium**
    - First measurement of D_s^+ v_2

BACK UP

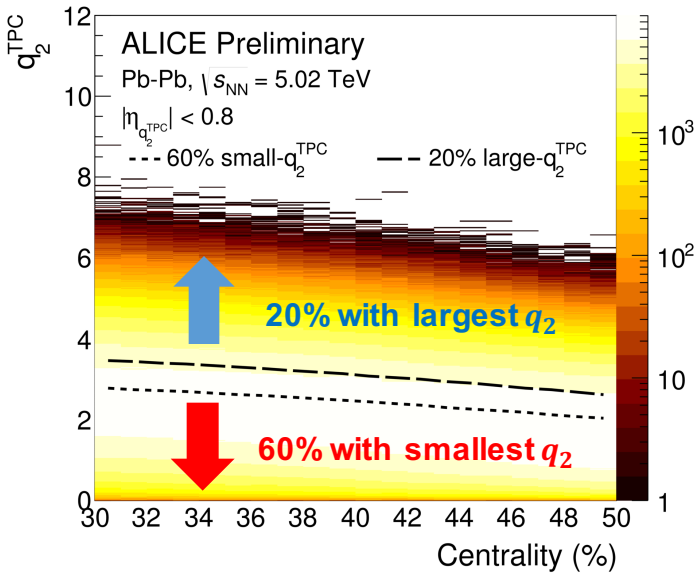
Poster ID: 116 by A.Festanti

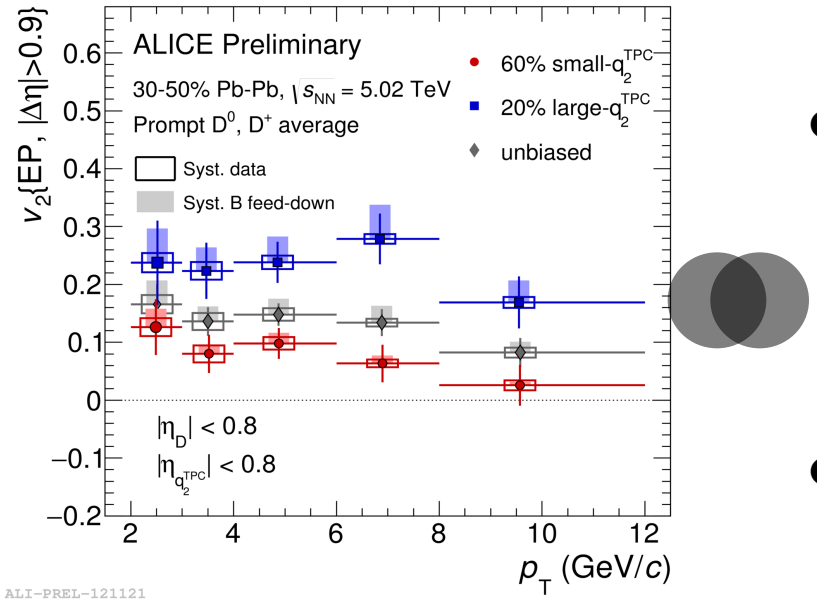
Event Shape Engineering Analysis

- Event eccentricity quantified by q_2 which depends on **multiplicity** and **strength of the flow**

$$\langle q_2^2 \rangle \approx 1 + \langle (\mathbf{M} - 1) \rangle \langle (\boldsymbol{v_2^2} - \delta_2) \rangle$$

- **Opportunity to study the charm-quark coupling to the bulk of light quarks** by measuring v_2 in events with different q_2 values



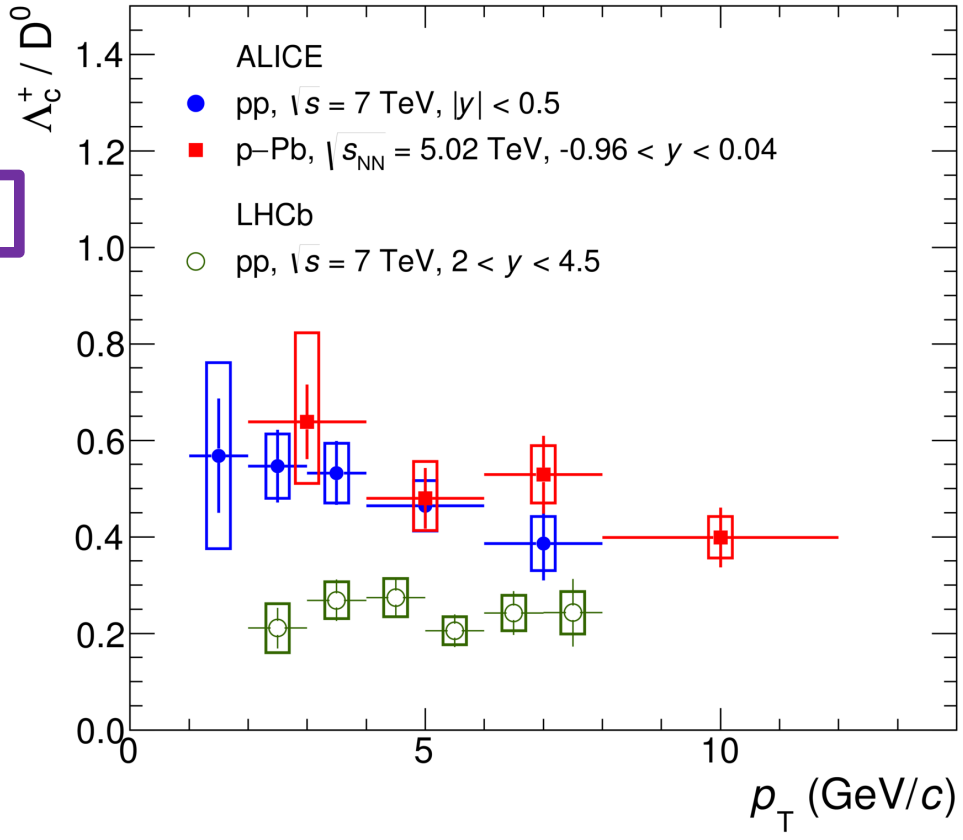


- **Significant separation** of D-meson v_2 in events with **large** and **small** q_2
  - ➢ Charm quarks are sensitive to the light-hadron **bulk collectivity** and event-by-event **initial condition fluctuations**
- Auto-correlations between q_2 and D mesons not removed completely

Λ_c^+/D^0 ratio compared with LHCb

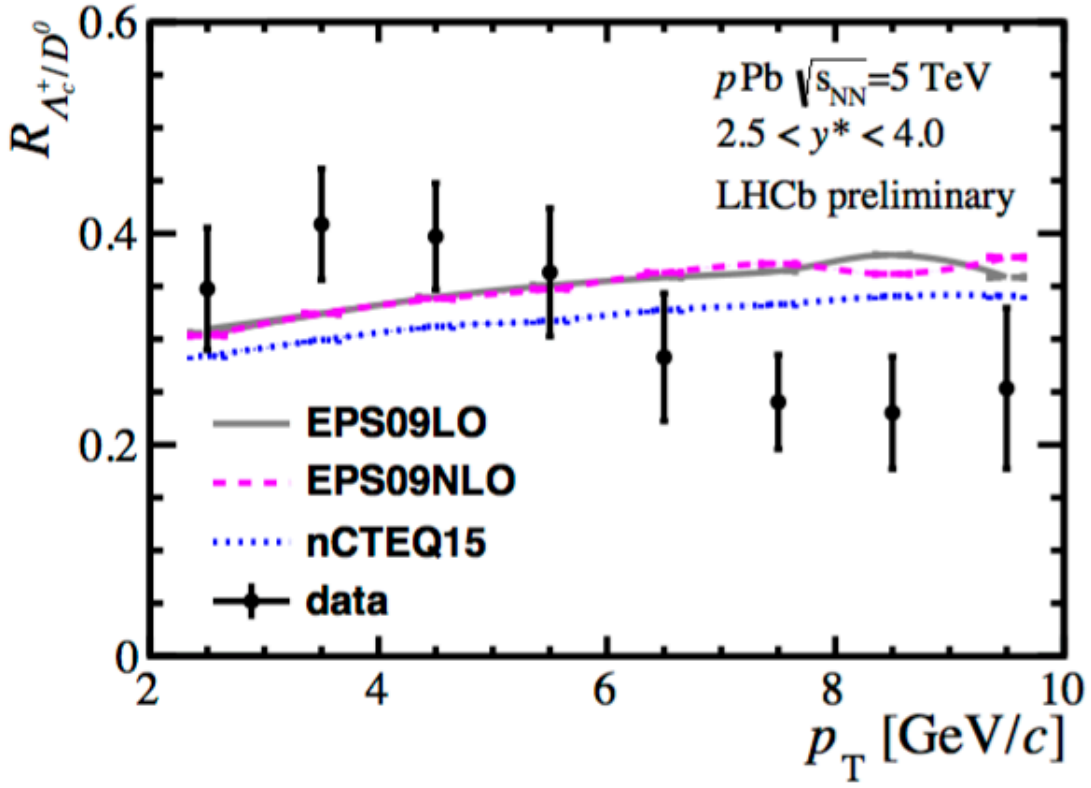
Published!

arXiv:1712.09581



LHCb:Nucl. Phys. B871 (2013) 1–20

p-Pb LHCb:CERN-LHCb-CONF-2017-005 (2017)

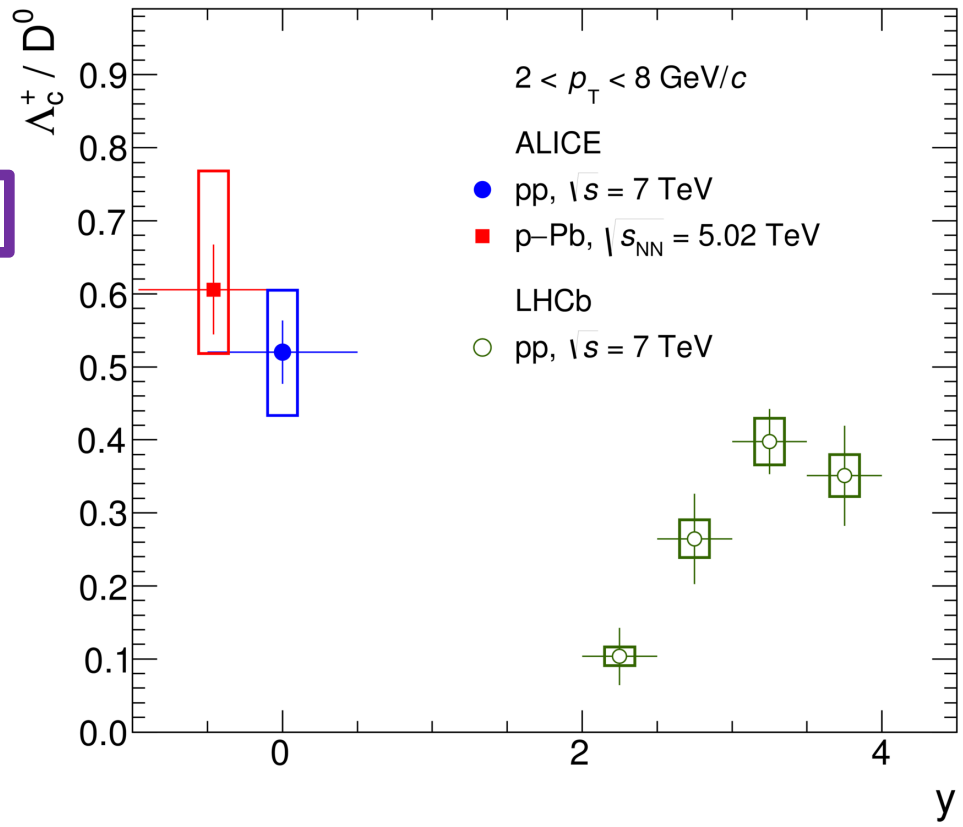


- ALICE measurement systematically **higher** than LHCb

Λ_c^+/D^0 ratio compared with LHCb

Published!

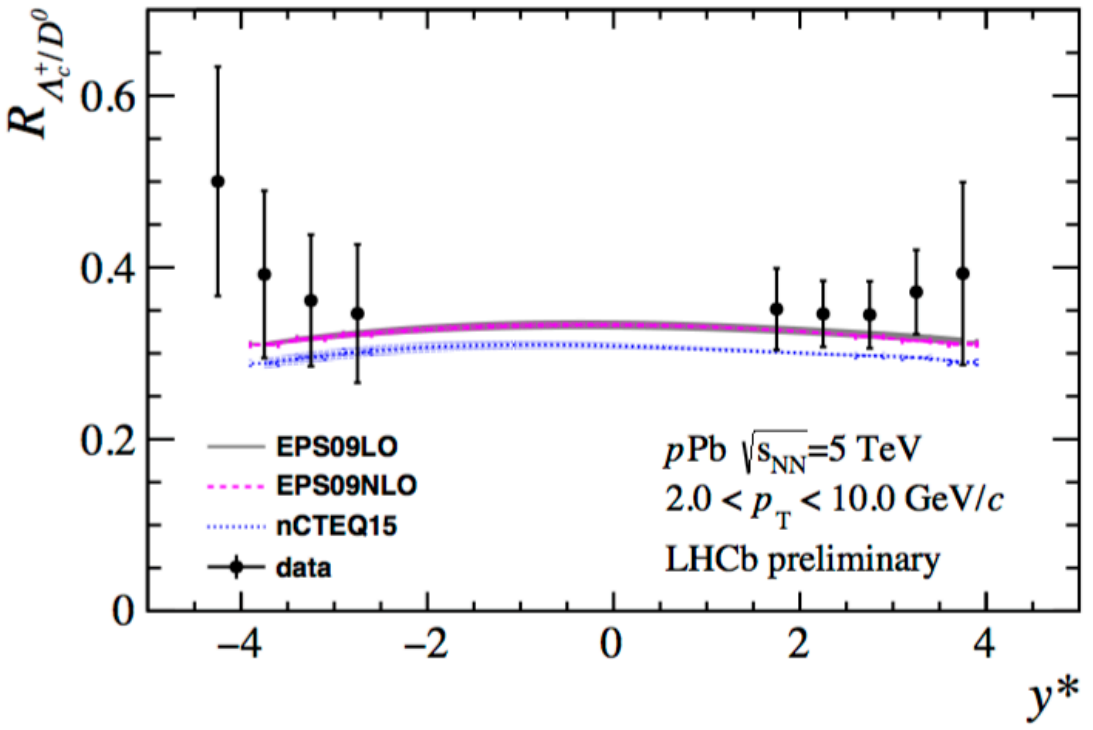
arXiv:1712.09581



ALI-PUB-141417

LHCb:Nucl. Phys. B871 (2013) 1–20

p-Pb LHCb:CERN-LHCb-CONF-2017-005 (2017)



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Λ_c^+ production in Pb-Pb compared with models