Heavy-flavour production measurements in pp and Pb-Pb collisions in ALICE

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Heavy quarks (charm, beauty)

▷ are produced at the early stages of the collision ($\tau_c \sim 0.08$ fm/c, $\tau_b \sim 0.02$ fm/c) via hard scattering

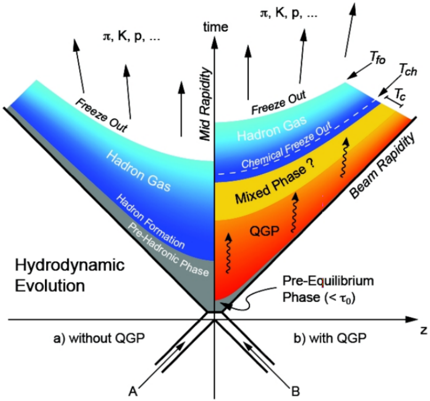
▷ have large bare masses ($m_c \sim 1.3$ GeV/c^2, $m_b \sim 4.2$ GeV/c^2)

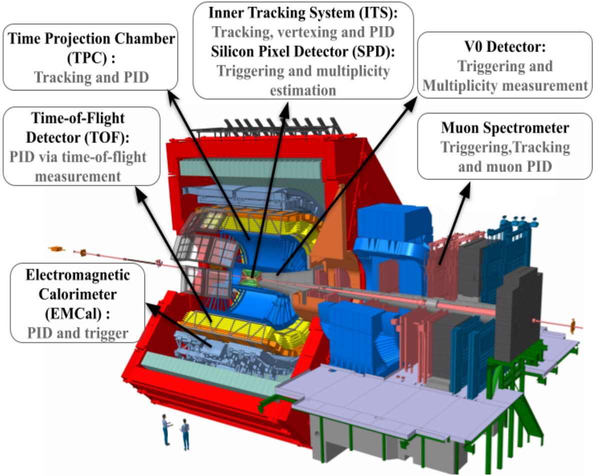
pp collisions:

- Test perturbative QCD calculations
- Baseline reference for heavy-ion studies
- Study hadronization mechanisms in vacuum
  [See talk by R. Bala]

Pb–Pb collisions:

- Heavy quark interaction with the medium constituents
  → Studied through nuclear modification factor (R_{AA}) and anisotropic flow (v_2, v_3, ...) measurements
- Study hadronization mechanisms in presence of a medium





[P.A. Zyla et al. (Particle Data Group), Prog. Theor. Exp. Phys. 2020, 083C01 (2020)]

Open heavy-flavor production discussed in this talk via:

$\mathbf{D^0}(\mathbf{c\bar{d}}) \rightarrow \mathrm{K}^-\pi^+$

$\mathbf{D^+}(\mathbf{c\bar{u}}) \rightarrow \mathrm{K}^-\pi^+\pi^+$

$\mathbf{D^{*+}}(\mathbf{c\bar{d}}) \rightarrow \mathrm{D}^0\pi^+$

$\mathbf{D_s^+}(\mathbf{c\bar{s}}) \rightarrow \mathrm{K}^-\mathrm{K}^+\pi^+$

$\mathbf{\Lambda_c^+}(\mathbf{udc}) \rightarrow \mathbf{pK}^-\pi^+$

$\rightarrow \mathbf{pK_s^0}$

Non-prompt mesons (baryons)

$\rightarrow$ Mesons (baryons) from beauty hadron decays

Nuclear modification factor (R_{AA}) in Pb–Pb

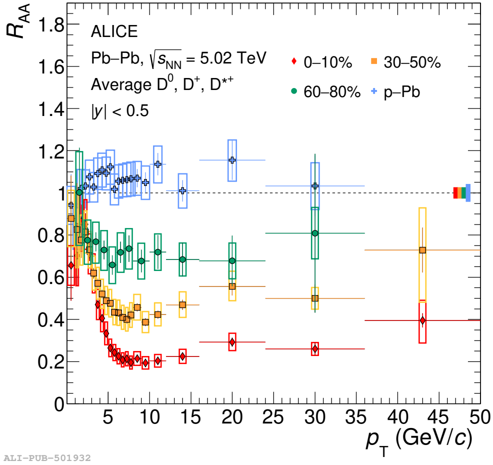
- **Suppression increases** from peripheral to central collisions (for $p_T \gtrsim 3$ GeV/c)

→ Due to **increasing density**, **size**, and **lifetime** of **medium**

- R_{pPb} compatible with unity within uncertainties

→ Suppression observed in **Pb–Pb** collisions is to due **final-state effects**

Prompt $D^{0,+,*+}$



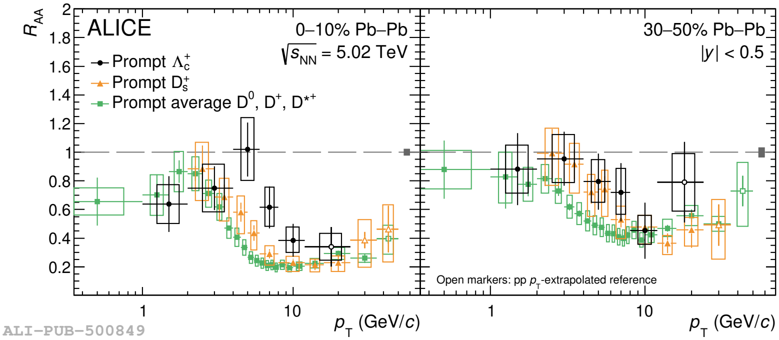
[ALICE, arxiv:2110.09420, JHEP 01 (2022) 174]

Nuclear modification factor (R_{AA}) in Pb–Pb

Prompt Λ_c^+

Prompt D_s^+

Prompt $D^{0,+,*+}$



[ALICE, arxiv:2112.08156, (Submitted to PLB)]

- **Hint of a hierarchy:** $R_{AA}(\Lambda_c^+) > R_{AA}(D_s^+) > R_{AA}(D)$, for $4 < p_T < 8$ GeV/c in most central collisions

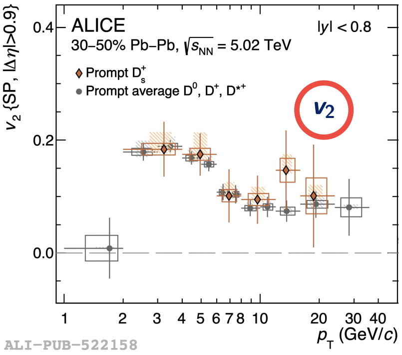
→ Indication that hadronization occurs also via *coalescence*? Interplay with *radial flow*?

More precise measurements needed before confirmation!!

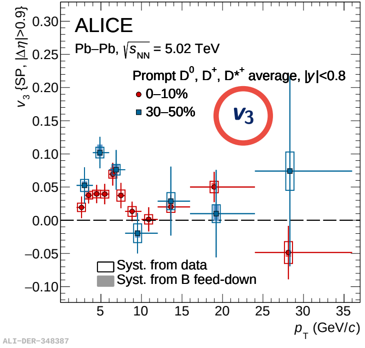
Prompt D_s^+: [ALICE, arxiv:2110.10006, (PLB 827 (2022) 136986)] Prompt non-strange D: [ALICE, arxiv:2110.09420, JHEP 01 (2022) 174]

Anisotropic flow (v_2, v_3) in Pb–Pb

Prompt D mesons



[ALICE, arxiv:2110.10006, PLB 827 (2022) 136986]



[ALICE, arxiv:2005.11131, PLB 813 (2021) 136054]

- **Positive v_2 and v_3 of D:** in 0-10% and 30-50% collisions

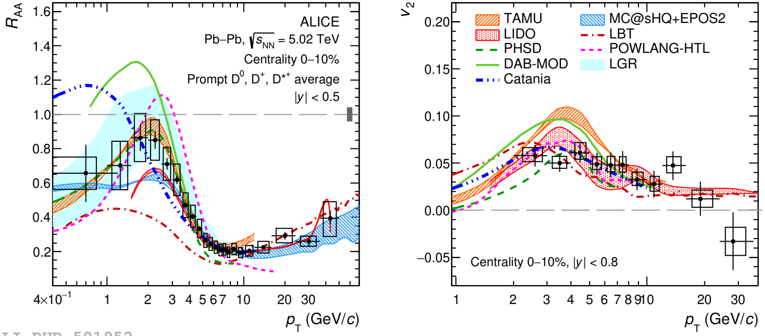
  → charm participates in collective motion

- **Current uncertainties too large** to draw conclusion about **potential difference** between D_s^+ and **non-strange D**!!

Model comparisons to understand which physics effects are relevant.

Prompt D mesons

TAMU: PRL 124, 042301 (2020)
LIDO: PRC 98, 064901 (2018)
PHSD: PRC 93, 034906 (2016)
Catania: PRC 96, 044905 (2017)
LBT: PLB 777 (2018) 255-259
LGR: EPJC 80 (2020) 7, 671
POWLANG: EPJC 75 (2015) 3, 121
MC@sHQ: PRC 91, 014904 (2015)
DAB-MOD:PRC 96, 064903 (2017)



ALI-PUB-501952

[ALICE, arxiv:2110.09420, JHEP 01 (2022) 174]

Model comparisons to understand which physics effects are relevant.

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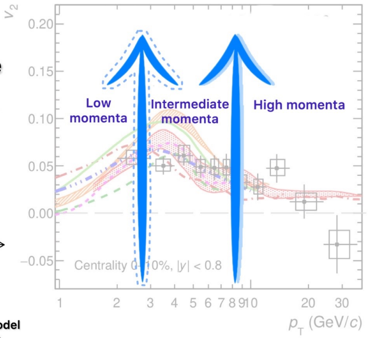
	Low momenta	Intermediate momenta	High momenta
Energy Loss	Elastic	Elastic+ Radiative	Radiative
Hadronization	⟵	Frag.+ Coalesence ⟶	Fragme-ntation
Thermalization	⟵	Flow (radial..) ⟶	×
Diffusion	⟵	✔ ⟶	⟵ × ⟶



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* => Detail comparison of data with model predictions in the following slides

[ALICE, arxiv:2110.09420, JHEP 01 (2022) 174]

Comparison with charm quark transport models

Model comparisons to understand which physics effects are relevant.

Prompt D mesons

TAMU: PRL 124, 042301 (2020)
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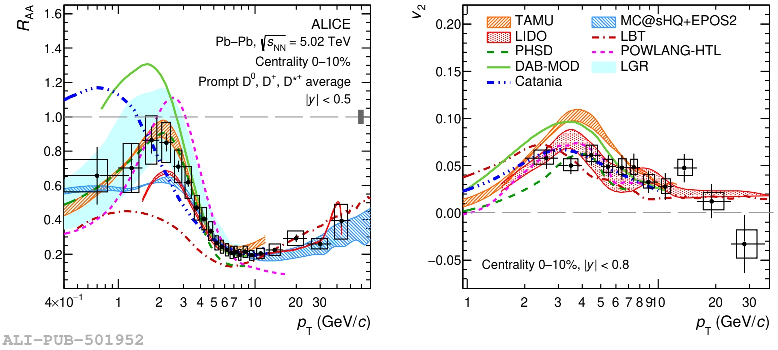


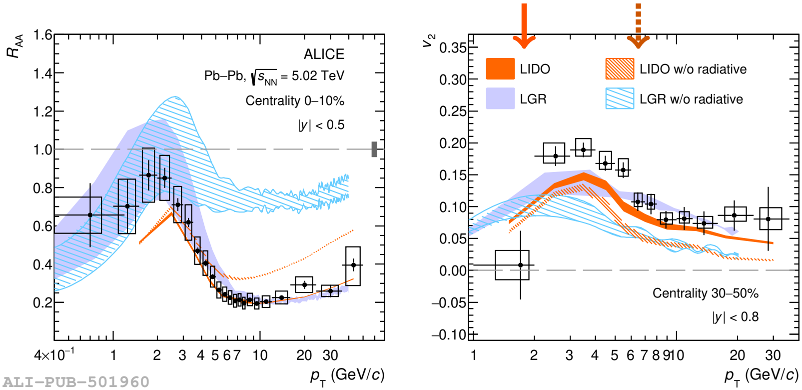
[ALICE, arxiv:2110.09420, JHEP 01 (2022) 174]

- Challenging to describe R_{AA} and v_2 simultaneously over the whole p_T range

Comparison with charm quark transport models

Prompt D mesons

With **Without** radiative energy loss

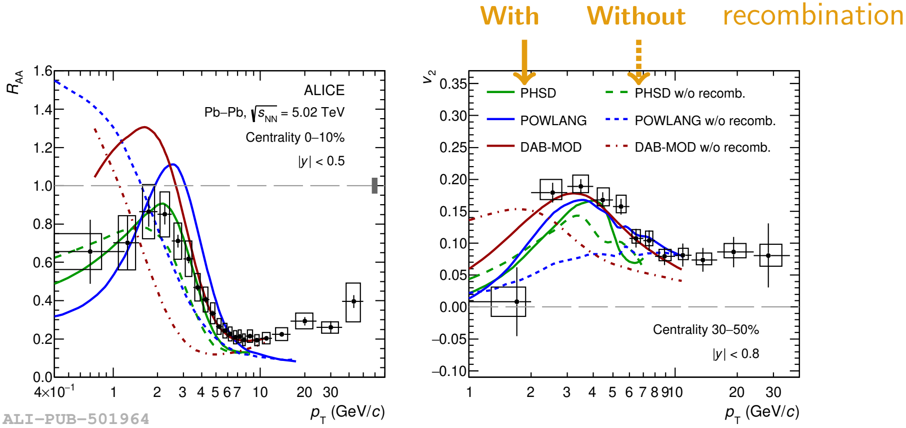


[ALICE, arxiv:2110.09420, JHEP 01 (2022) 174]

- **Radiative energy loss important** to describe intermediate and high p_T

Comparison with charm quark transport models

Prompt D mesons

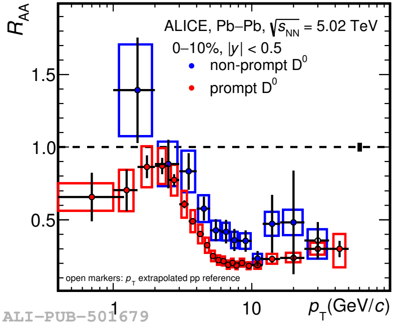


[ALICE, arxiv:2110.09420, JHEP 01 (2022) 174]

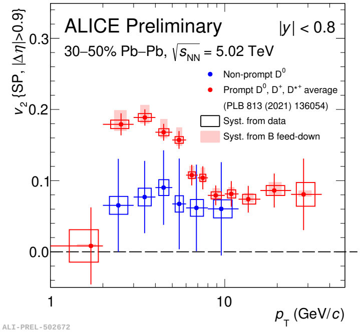
- **Hadronisation via recombination important** to describe low and intermediate p_T

Non-prompt D meson R_{AA} and v_2

Non-prompt D^0, Prompt D^0



[ALICE, arxiv:2202.00815, JHEP 12 (2022) 126]



- R_{AA} of **non-prompt D^0** systematically **higher** than the **prompt D^0** ($p_T \gtrsim$ 5 GeV/c)

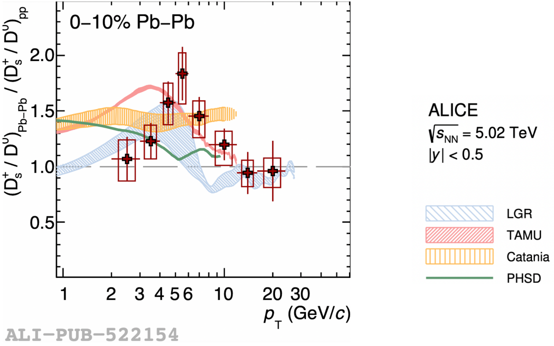
→ *beauty quarks loose less energy* than charm quarks because of their larger mass.

- **Hint of positive v_2 of non-prompt D^0**

→ beauty quark thermalised? Or due to recombination with light quarks?

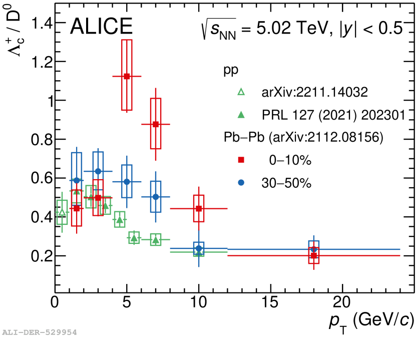
Charm hadronisation in Pb–Pb and pp collisions

Double ratio of prompt D_s^+/D^0 :



[ALICE, arxiv:2110.10006, PLB 827 (2022) 136986]

Prompt Λ_c^+/D^0:



[ALICE, arxiv:2112.08156, (Submitted to PLB)]

- **Agreement with models** that include:

→ *strangeness enhancement* and

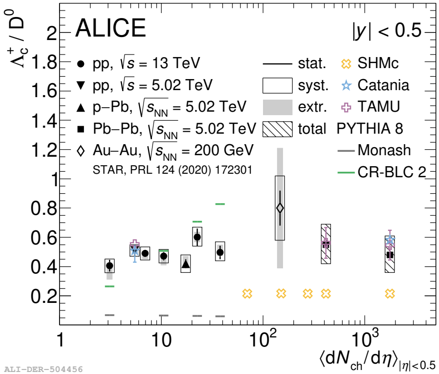
→ *fragmentation + recombination*

- **Increasing** trend from **pp**, to **semi-central** and **most central Pb-Pb** (at intermediate p_T)

→ Coalescence? Radial flow?

Charm hadronisation in Pb–Pb and pp collisions

p_{T}-integrated prompt Λ_c^+/D_0



TAMU: PRL 124, 042301 (2020)

SHMc: JHEP 07 (2021) 035

Catania: PRC 96, 044905 (2017)

PYTHIA 8 Monash: EPJC 74 (2014) 3024

PYTHIA 8 CR-BLC: JHEP 08 (2015) 003

No evidence of multiplicity dependence, from low (pp) to high (central Pb–Pb) multiplicity

→ Reproduced by **fragmentation + recombination** and **SHM** predictions

- Is the p_{T}-differential enhancement at intermediate p_{T} a consequence of **radial flow** only?

Summary

- **Charm production accessed via prompt D mesons and prompt Λ_c^+**

  → Charm quarks **interact** with medium via **collisional** and **radiative** processes

  → Charm quarks **participate** in the collective motion, i.e. **are thermalised**

  → Charm quarks **hadronise** via **recombination + fragmentation**

- **Beauty production accessed via non-prompt D mesons**

  → Important constraint of mass dependence of ΔE

More studies needed to discriminate among different theoretical descriptions and physics mechanisms.

Back-up

Summary of charm quark transport model

	Energy Loss: Collisional	Radiative	Initial state effect: [nPDF]	Hadronization: [Frag.+Recom.]
TAMU	✔	✘	✔	✔
PHSD	✔	✘	✔	✔
Catania	✔	✘	✔	✔
POWLANG-HLT	✔	✘	✔	✔
LIDO	✔	✔	✔	✔
LGR	✔	✔	✔	✔
LBT	✔	✔	✔	✔
MC@sHQ+EPOS2	✔	✔	✔	✔
DAB-MOD	✔	✔	✘	✔

Difference in models due to differences in implementations of:

- Interactions of c-quark with medium: [*Table*]
- Considered nPDFs
- Ideal or viscous hydro
- Various recombination approaches e.g., Wigner, Resonance-recombination