



# Probing parton propagation in heavy-ion collisions with ALICE heavy-flavour measurements

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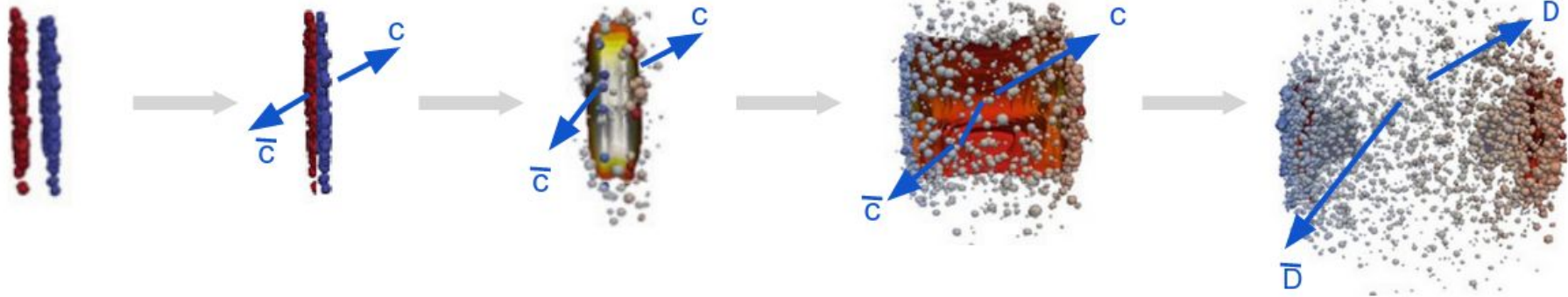
**Ravindra Singh, on behalf of the ALICE Collaboration**  
**Indian Institute of Technology Indore (India)**  
**05/09/2023**

**Quark Matter 2023**  
**Sep 3 – 9, 2023 Houston, Texas, USA**

# Heavy quarks (HQ) in heavy-ion collisions

**Heavy quarks (charm and beauty) carry information of:**

- Initial stage
- QGP properties
- Hadronization mechanisms
- Rescattering in hadronic phase



## Initial stage

- nPDFs
- EM field

## Production:

- Hard scattering ( $< 0.1$  fm/c)
- Calculable with pQCD  $\rightarrow$  calibrated probe

## Energy loss in the QGP:

- Collisional and radiative
- Low  $p_T$ : Brownian motion  $\rightarrow$  spatial diffusion coefficients

## Mass hierarchy?

- Dead-cone effect

## Hadronization:

- Coalescence + fragmentation

# Study of open heavy-flavours with ALICE detector



**Open heavy-flavour hadrons** → Heavy quark (c/b) hadronize with light quarks (q)



**D meson**



**$\Lambda_c$  baryon**

## Measured:

- Reconstructing HF hadrons from hadronic and semileptonic decays
- Leptons from HF hadron decays ( $c, b \rightarrow e, \mu$ )

## Time Projection Chamber ( $|\eta| < 0.9$ )

- Tracking
- PID via specific energy loss

## V0 detectors

- Triggering,
- Multiplicity estimator  
 $2.8 < \eta < 5.1$  (V0A)  
 $-3.7 < \eta < -1.7$  (V0C)

## Calorimeter (EMCal & DCal) ( $|\eta| < 0.7$ )

- Trigger
- Electron PID via energy measurement and shower shape

## Inner Tracking System ( $|\eta| < 0.9$ )

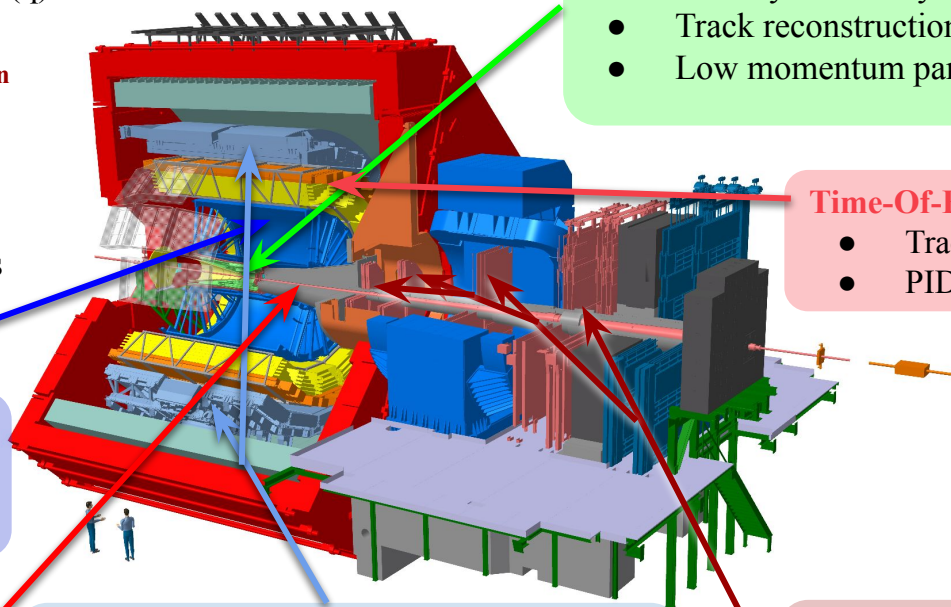
- Primary and decay vertices reconstruction
- Track reconstruction
- Low momentum particle identification

## Time-Of-Flight detector ( $|\eta| < 0.9$ )

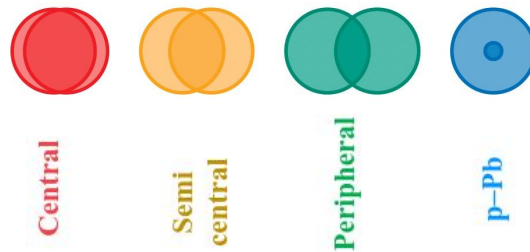
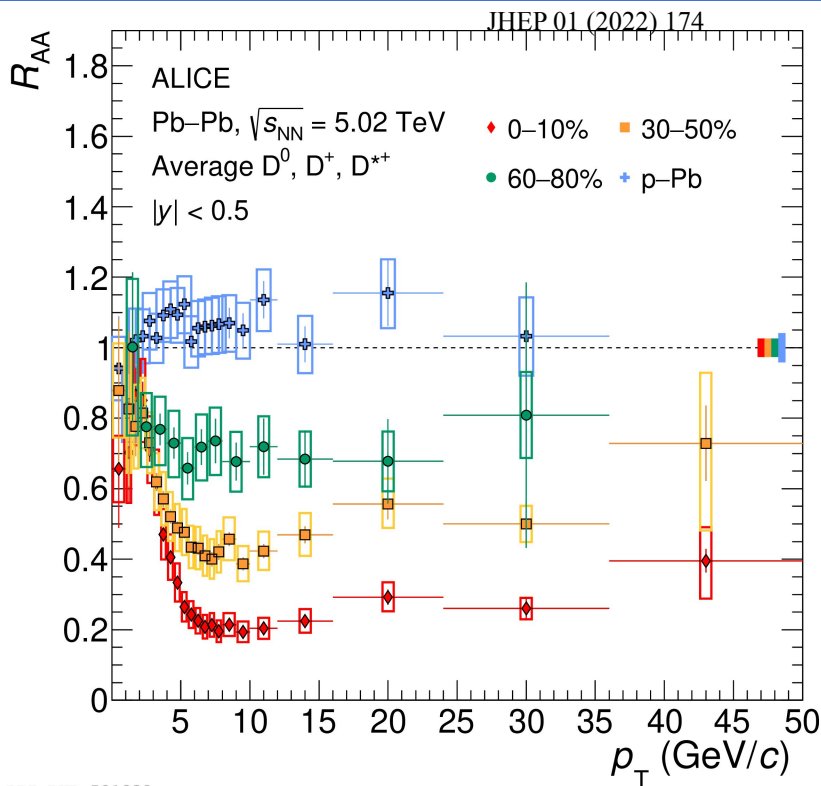
- Tracking
- PID through time-of-flight

## Muon spectrometer

- Muon reconstruction  
 $-4.0 < \eta < -2.5$



# Nuclear modification factor ( $R_{AA}$ ) dependence on system size



$$R_{AA}(p_T) = \frac{1}{\langle T_{AA} \rangle} \frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T},$$

$R_{AA} = 1 \rightarrow$  No modification  
 $R_{AA} < 1 \rightarrow$  Nuclear effects

- $\langle T_{AA} \rangle \rightarrow$  average nuclear overlap function
- $d\sigma_{pp}/dp_T \rightarrow$  production cross section in proton-proton collisions
- $dN_{AA}/dp_T \rightarrow p_T$ -differential production yield in heavy-ion collisions

Nuclear modification factor in different centrality classes in  
**Pb-Pb collisions (0-10%, 30-50%, 60-80%) + p-Pb collisions**

**Suppression increasing with collision centrality  
 due to increasing density, size, and lifetime of the medium**

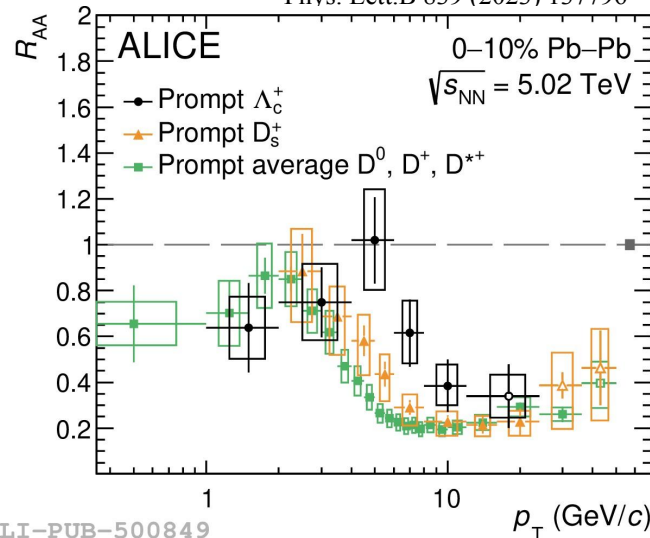
ALI-PUB-501932

Pb-Pb 60-80%: JHEP 10 (2018) 174

p-Pb: JHEP 12 (2019) 092

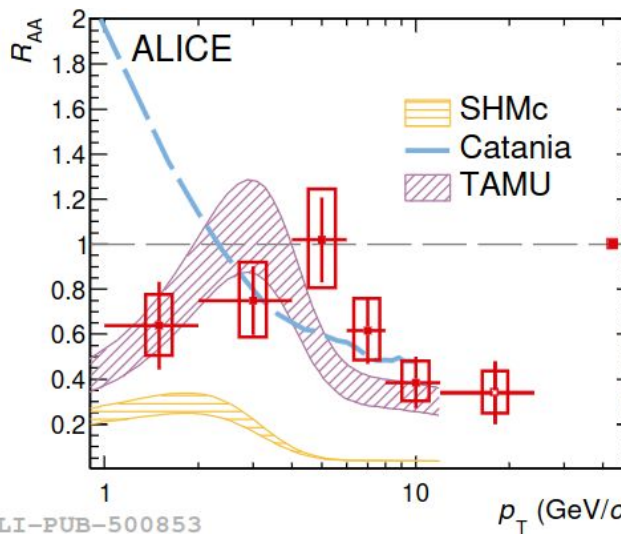
$R_{AA}(\Lambda_c^+)$ , 0-10%

Phys. Lett.B 839 (2023) 137796



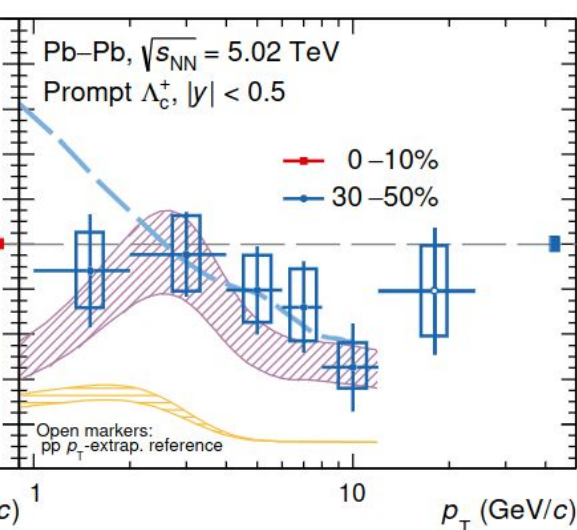
ALI-PUB-500849

$R_{AA}(\Lambda_c^+)$ , 0-10%



ALI-PUB-500853

$R_{AA}(\Lambda_c^+)$ , 30-50%

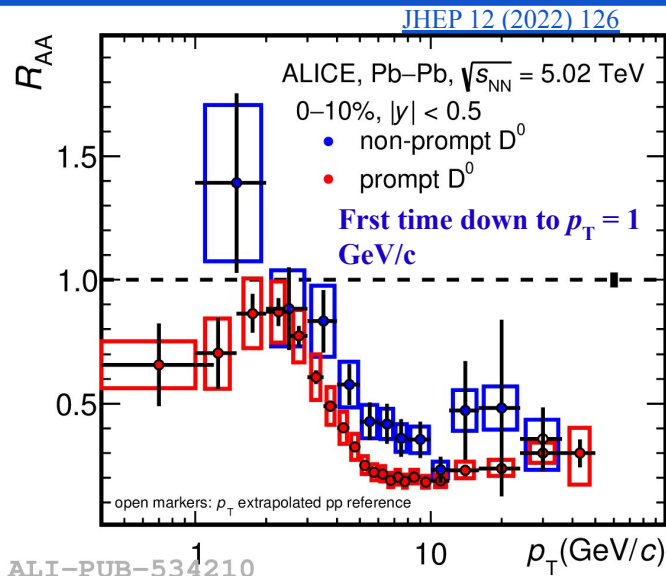


TAMU: PLB 735 445 (2014)  
Catania: EPJC 78 (2018) 4, 348  
SHMc: JHEP 07 (2021) 035

- $R_{AA}(\Lambda_c^+) > R_{AA}(D_s^+) > R_{AA}(D^0, D^+, D^{*+})$  for  $4 < p_T < 10$  GeV/c (**recombination and radial flow**)
- **TAMU** → good description of the  $R_{AA}$  over full  $p_T$  range
- **Catania** → describes the data for  $p_T > 2$  GeV/c
- **SHMc** → underestimates the data → corona description could be further optimized?

charm baryon production → Poster session(165, 177, 189, 491, 560)  
Talk → 16:50: Jianhui Zhu  
06/09/2023

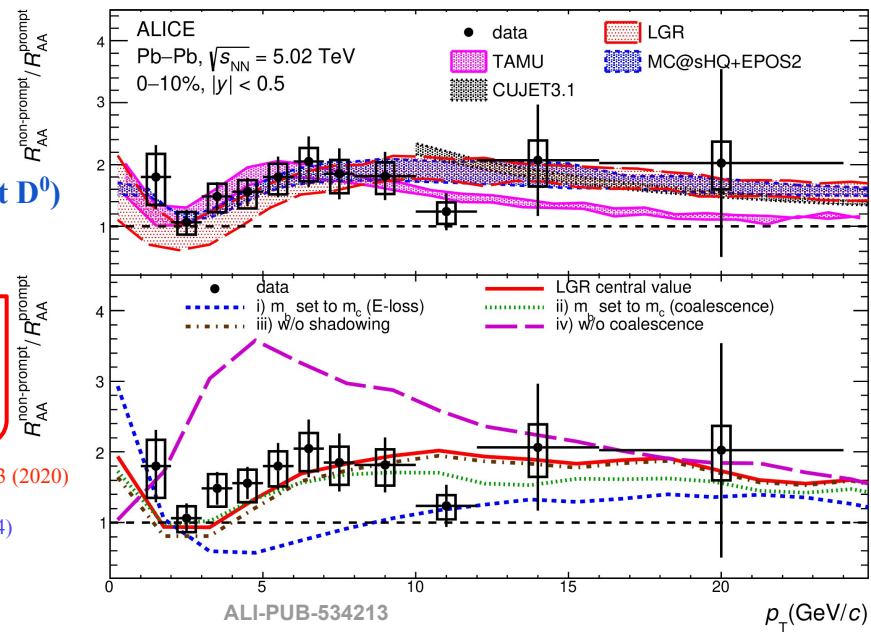
# Beauty hadron energy loss and hadronization



$p_T$  shift  $\rightarrow p_T(\text{non-prompt } D^0)$   
 $< p_T(\text{parent B meson})$

non-prompt  $D$  production  
 $\rightarrow$  Poster session(138)  
Renu Bala  
06/09/2023

LGR: EPJC 80 671 (2020), EPJC 80 1013 (2020)  
TAMU: PLB 735 445 (2014)  
MC@sHQ+EPOS2: PRC 89 01490 (2014)  
CUJET3.1: CPC 43 044101 (2019)



Hint of  $R_{AA}(\text{beauty hadron}) > R_{AA}(\text{charm hadron})$  for  $p_T < 12$  GeV/c

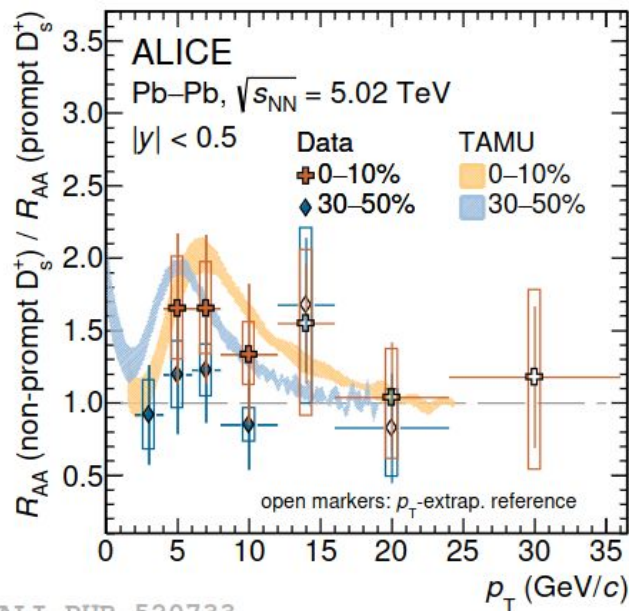
- Mass dependence of in-medium energy loss  $\rightarrow \Delta E_b < \Delta E_c$
- Different shadowing or hadronization via recombination

LGR configuration  $\rightarrow$  radiative+collisional energy loss, hadronization via fragmentation+coalescence

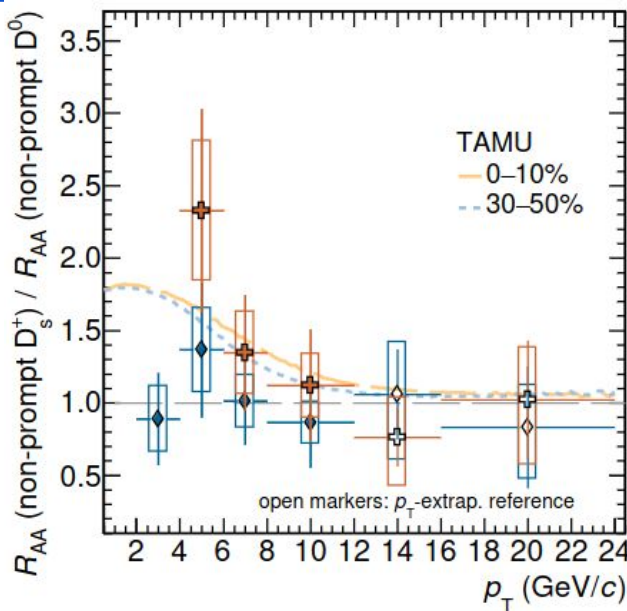
- if  $m_b \rightarrow m_c$  for E-loss calculation: Ratio  $\approx 1 \rightarrow$  **relevant role of dead-cone effect**
- **Prompt- $D^0$  formation via coalescence explains the minimum (2-3 GeV/c) observed on data**



# Extending for $D_s^+$ meson



ALI-PUB-520733



ArXiv:2204.10386

TAMU: PLB 735 445 (2014)

## TAMU:

- Transport: Langevin equation
- Hadronisation: recombination + fragmentation
- describes the data within the uncertainties

- 0-10%: Ratio shows hint of enhancement at  $4 < p_T < 12$  GeV/c with significance  $1.6\sigma \rightarrow$  Mass effect

- 0-10%: Ratio suggests hint of enhancement with a significance of  $1.7\sigma$  in the  $4 < p_T < 12$  GeV/c  $\rightarrow$  recombination + strangeness-rich environment

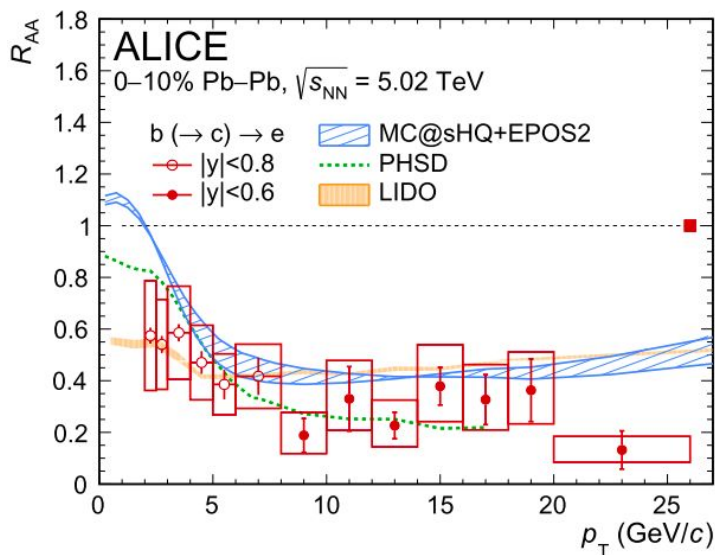
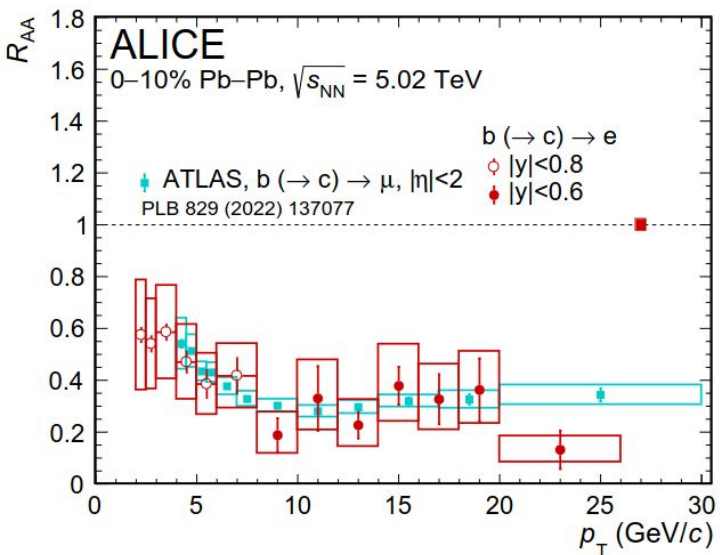
- 30-50%: Model predicting same observation as 0-10%  $\rightarrow$  Experimental results require more precise measurement
- Direct access to B meson down to low  $p_T$  will also help in investigating further these effects  $\rightarrow$  Run 3 measurements

# Energy loss of beauty-decay electrons in the medium ( $R_{AA}$ )



ArXiv:2211.13985

$b \rightarrow c \rightarrow e \rightarrow$  electrons from beauty-hadron decay

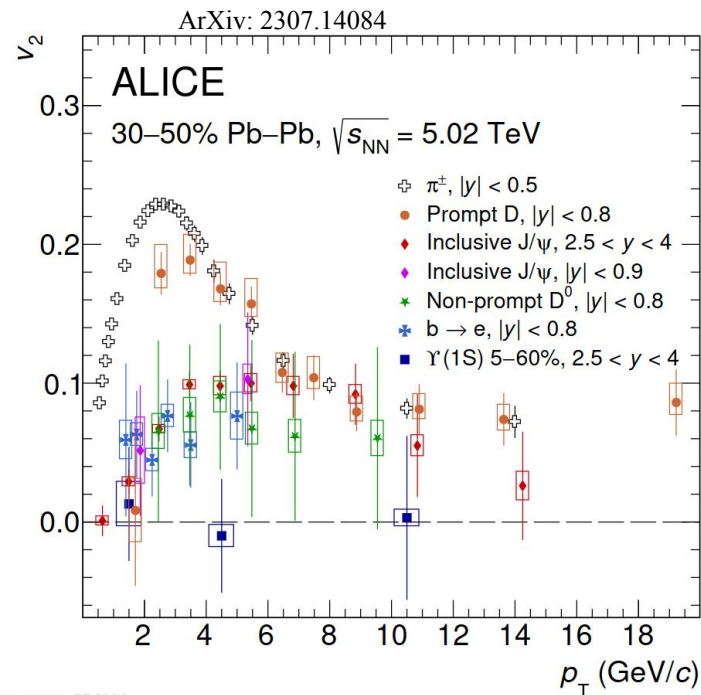


- Significant suppression of  $b \rightarrow c \rightarrow e$  in Pb–Pb collisions at intermediate and high  $p_T$
- No significant  $p_T$  dependence ( $p_T > 8$  GeV/c) within uncertainties

- **ALICE**  $R_{AA}(b \rightarrow c \rightarrow e) \approx$  **ATLAS**  $R_{AA}(b \rightarrow c \rightarrow \mu)$   $\longrightarrow$  **no dependency on decay channels**
- **All models provide good description of data within uncertainty**



# Mass hierarchy of elliptic flow ( $v_2$ )



Positive  $v_2$  for open/hidden charm and  $b$  ( $\leftarrow e$ )

→ participate in collective motion

$$dN/d\phi \approx 1 + 2 \sum_n v_n \cos[n(\phi - \Psi_n)]$$

- **Low  $p_T < 3$  GeV/c** :  $v_2 > 0 \rightarrow$  thermalisation of charm quarks
  - Mass hierarchy  $\rightarrow v_2(Y) \lesssim v_2(b \rightarrow e) \approx v_2(J/\psi) < v_2(D) < v_2(\pi)$
- **Intermediate  $3 < p_T < 6$  GeV/c** : contribution from hadronization via coalescence with light quarks?
  - $v_2(J/\psi) < v_2(D) \approx v_2(\pi)$
  - $v_2(Y) < v_2(b \rightarrow e)$
- **High  $p_T > 8$  GeV/c** : path-length dependence of in-medium energy loss
  - $v_2(J/\psi) \approx v_2(D) \approx v_2(\pi)$

- $v_2(\text{non-prompt } D^0) \approx v_2(b \rightarrow e) < v_2(\text{prompt } D^0) \rightarrow$  lower degree of thermalisation for beauty quarks

ALICE Non-prompt D: arXiv:2307.14084

ALICE Prompt D: PLB 813 (2021) 136054

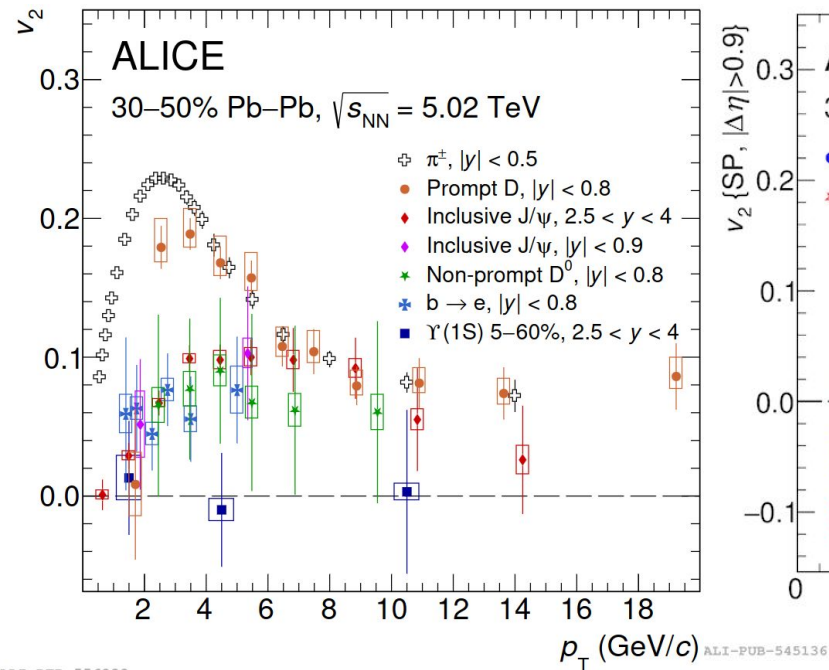
ALICE  $\pi$ : JHEP 1809 (2018) 006

ALICE  $b \rightarrow e$ : PRL 126 (2021) 16200

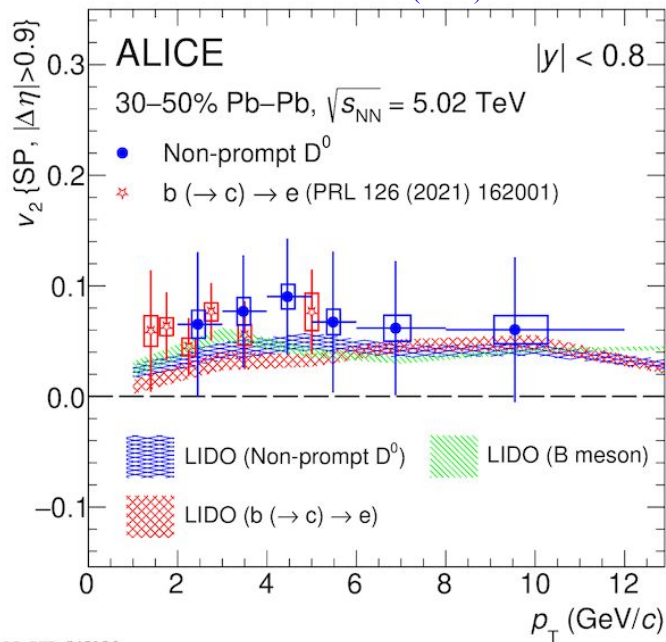
ALICE  $Y(1S)$ : PRL 123 (2019) 192301

ALICE  $J/\psi$ : JHEP 10 (2020) 141

# Beauty flow from light-quark recombination?



LIDO: PRC 98 064901 (2018)



## LIDO describes the data

- **Hadronization**  $\rightarrow$  **coalescence** + **fragmentation**
  - **Energy loss**  $\rightarrow$  **collisional** + **radiative**
- $v_2$  of beauty does not significantly depend on beauty-hadron decay kinematics

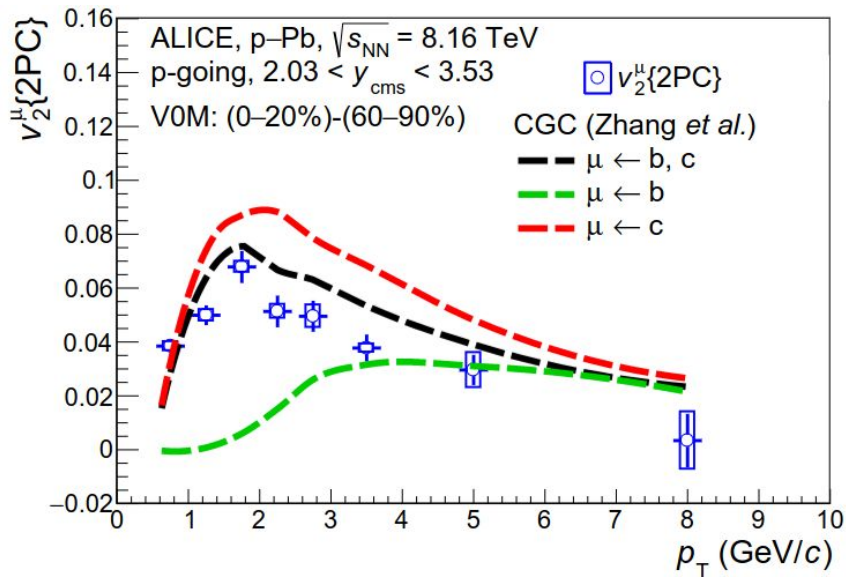
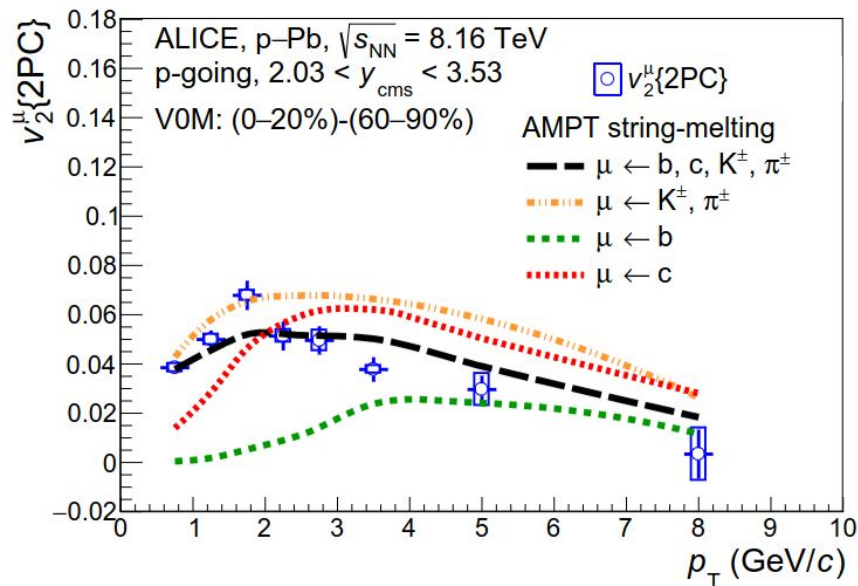
- $v_2(\text{non-prompt } D^0) > 0$  with significance of  $2.7\sigma$
- $v_2(\text{non-prompt } D^0) < v_2(\text{prompt } D) >$  with significance of  $3.2\sigma$  in the interval  $2 < p_T < 8$  GeV/c

ALICE Non-prompt D: arXiv:2307.14084  
ALICE Prompt D: PLB 813 (2021) 136054  
ALICE  $\pi$ : JHEP 1809 (2018) 006  
ALICE  $b \rightarrow e$ : PRL 126 (2021) 16200  
ALICE  $Y(1S)$ : PRL 123 (2019) 192301  
ALICE  $J/\psi$ : JHEP 10 (2020) 141

# Collectivity in small systems → Inclusive muon $v_2$ in p-Pb



ArXiv: 2210.08980



- Positive  $v_2$  with a significance of up to  $\sim 12\sigma$  ( $2 < p_T < 6$  GeV/c) → collectivity in small systems
- Small  $v_2$  at high  $p_T$  ( $6 < p_T < 10$  GeV/c) → beauty-dominated region
- $v_2$  in AMPT → flow explained by the anisotropic parton escape mechanism
- CGC → qualitative agreement with data suggest possible contributions from initial-state effects

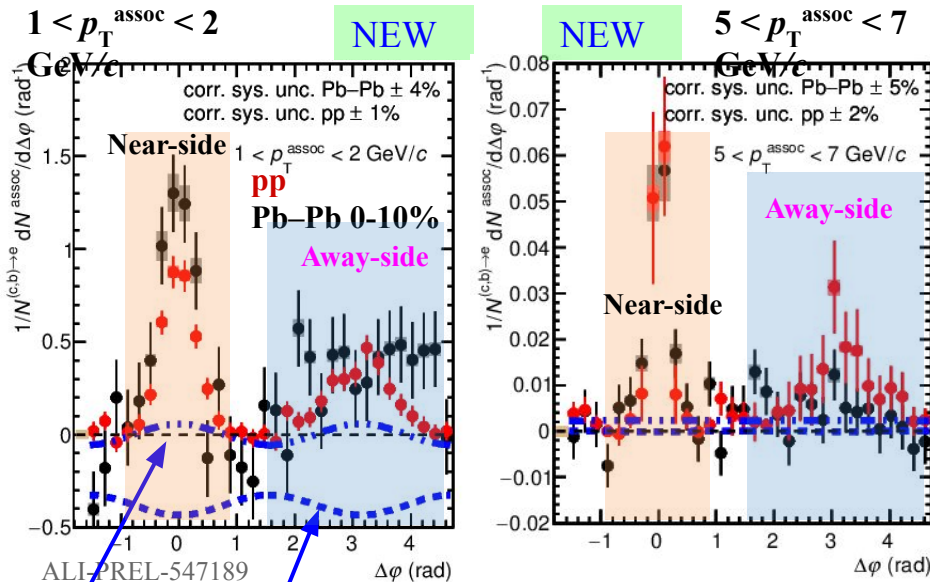
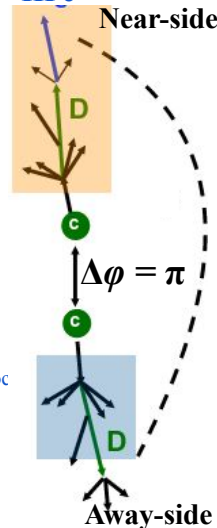
# Jet fragmentation using HFe correlation at $\sqrt{s}_{NN} = 5.02$ TeV



HFe  $\rightarrow$  electrons from heavy-flavour hadron decay

HF jet or HF correlation  $\rightarrow$  direct access to the initial parton kinematics

$$\Delta\phi = (\phi_{\text{HFe}} - \phi_h)$$



Maximum and minimum sys. of baseline  $\rightarrow$  contribution from elliptic flow

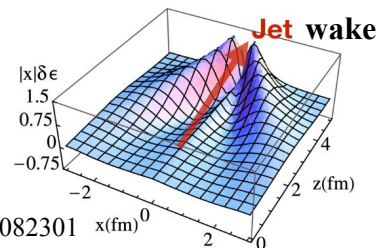
## What can we learn?

- Jet fragmentation and modification of fragmentation function in Pb–Pb collisions
- Jet modification in medium?
  - Wake effect  $\rightarrow$  enhancement of low  $p_T^{\text{assoc}}$  associate particle in jet direction
  - Jet quenching  $\rightarrow$  suppression of high  $p_T^{\text{assoc}}$  associate particle at away-side peak

- Observed hint of suppression of yield at high  $p_T^{\text{assoc}}$  away-side peak  $\rightarrow$  Jet quenching

Poster session(146)  
Amanda N Flores  
06/09/2023

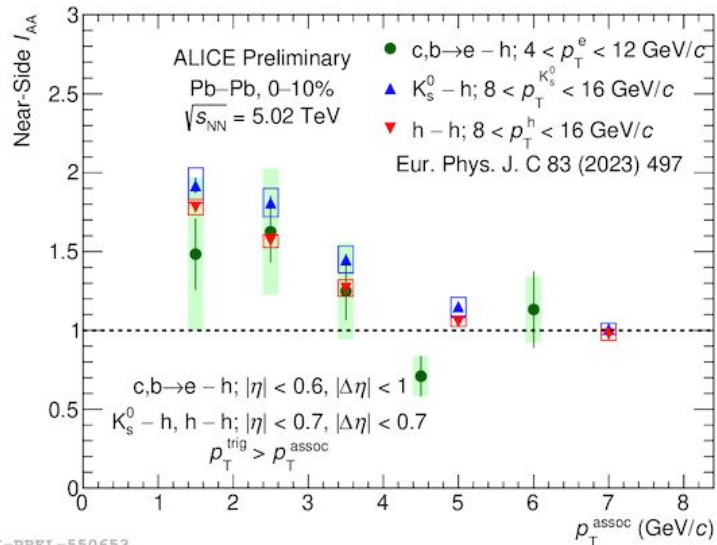
Phys.Rev.Lett. 127 (2021) 8, 082301



# $I_{AA}$ comparison with light-flavour correlation

Eur. Phys. J. C 83 (2023) 497

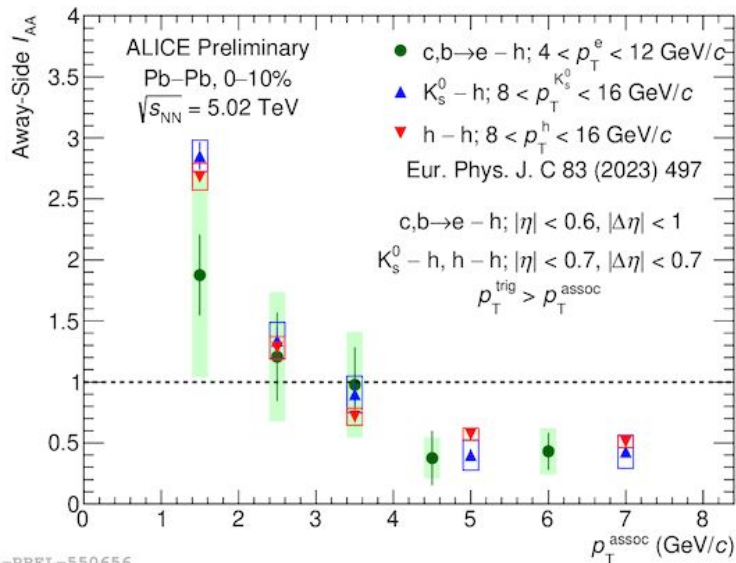
NEW



ALI-PREL-550653

$$I_{AA} = \frac{Y_{Pb-Pb}}{Y_{pp}}$$

NEW



ALI-PREL-550656

- **HFe correlation:**  
Initiated by heavy quarks
- **LF correlation:**  
-Initiated mainly by gluons
- **Different trigger particle  $p_T \rightarrow$  parton  $p_T$  shift between LF and HF measurements**

- **HFe-h  $I_{AA}$  consistent with LF  $I_{AA}$  within uncertainty**
  - **Consistent with unity within uncertainties**

- **Jet quenching for AS observed at high- $p_T^{assoc}$  ( $p_T^{assoc} > 4$  GeV/c)**

- Mass-dependent energy loss

- Observed hierarchy of charm hadron  $R_{AA}$ :
  - $R_{AA}(\Lambda_c^+) > R_{AA}(D_s^+) > R_{AA}(D) \rightarrow$  recombination and radial flow
- $R_{AA}(\text{non-prompt } D^0) > R_{AA}(\text{prompt } D^0) \rightarrow$  dead-cone effect

*Thank  
you* 

- Collectivity in heavy-ion collisions

- Strong coupling of charm quark with QGP constituents at low  $p_T \rightarrow$  charm thermalization in the medium
- Small  $v_2$  for beauty  $\rightarrow$  weaker thermalization
- $v_2 > 0$  for inclusive muon in high multiplicity p-Pb collisions  $\rightarrow$  presence of collective-like effects in small systems also in the HF sector

- Hint of suppression at high  $p_T$  in away-side HFe-h correlation peak  $\rightarrow$  hint of jet quenching

- Models predictions:

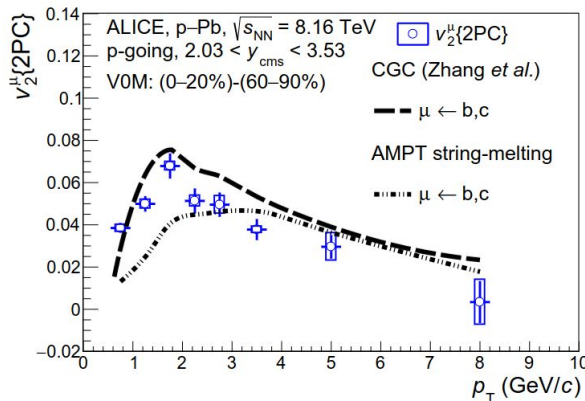
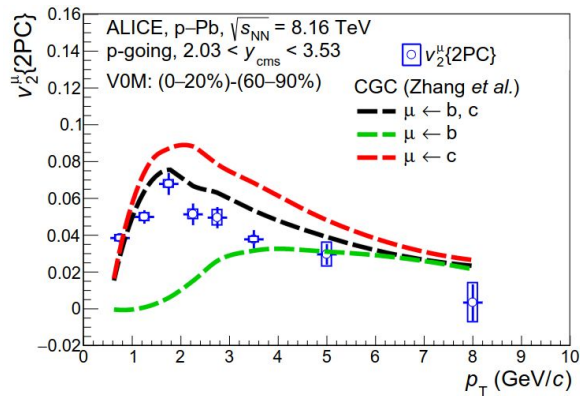
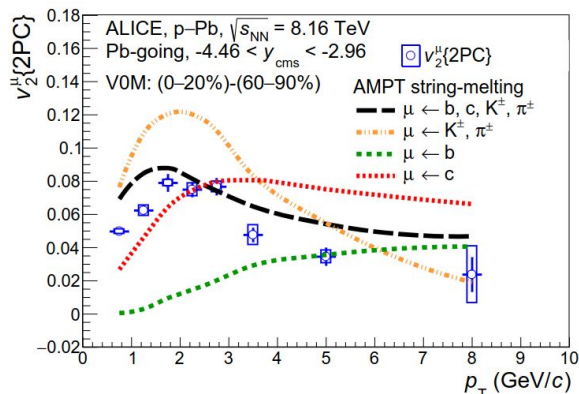
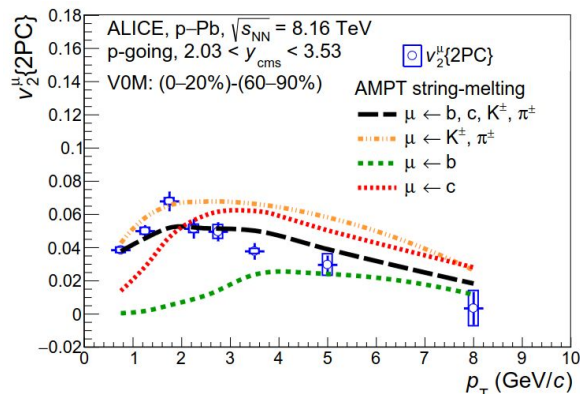
- Radiative and collisional energy-loss mechanism  $\rightarrow$  describe the energy-loss in the medium
- Hadronization with coalescence + fragmentation  $\rightarrow$  describe the data



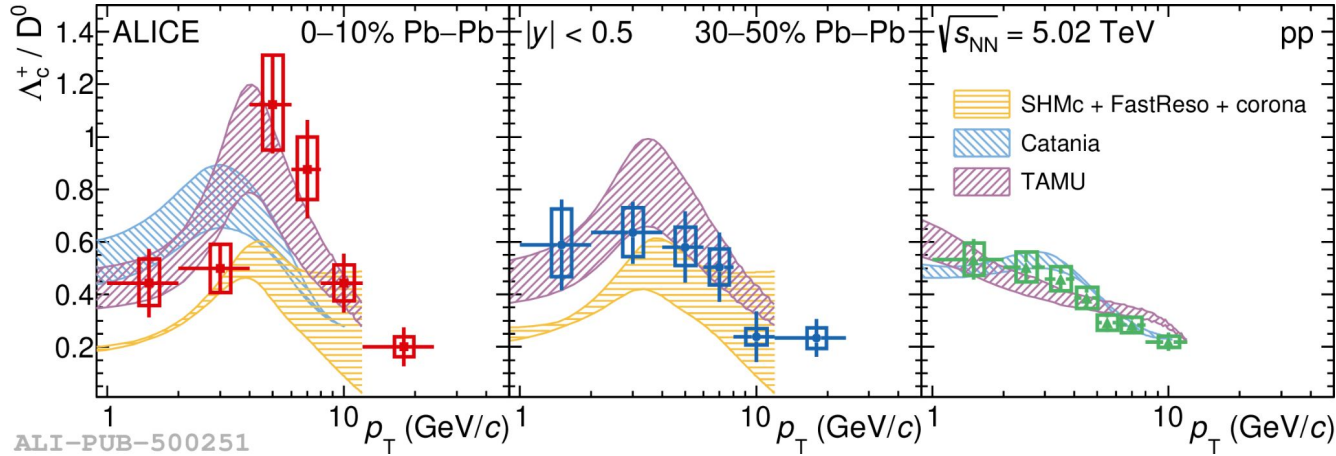
# Back-up slides



# Collectivity in small systems → Inclusive muon $v_2$ in p-Pb



- A hint for a higher elliptic flow signal at backward rapidity (Pb-going) → rapidity-dependent flow-vector fluctuations
- Positive  $v_2$  with a significance of upto  $\sim 12\sigma$  ( $2 < p_T < 6$  GeV/c)
- Small  $v_2$  at high  $p_T$  ( $6 < p_T < 10$  GeV/c) → beauty dominant region
- $v_2$  in AMPT → the anisotropic parton escape mechanism → partons have a higher probability to escape along the shorter axis of the interaction zone
- CGC → qualitative agreement with data suggest possible contributions from initial-state effects



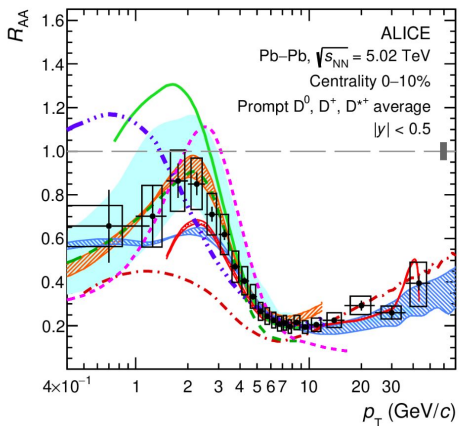
$\Lambda_c^+ / D^0$  ratio in central Pb-Pb and in pp:

For  $4 < p_T < 8$  GeV/c,  $3.7\sigma$  significance for  $\Lambda_c^+$  enhancement in 0-10% collisions

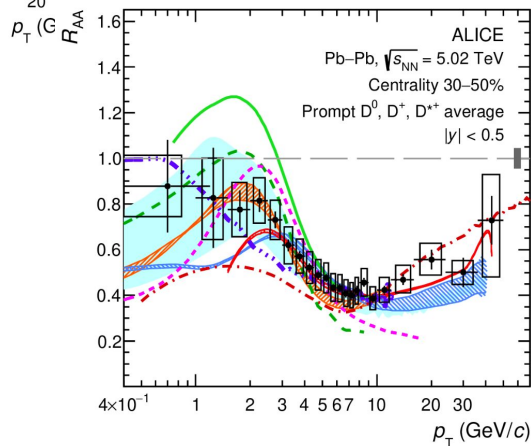
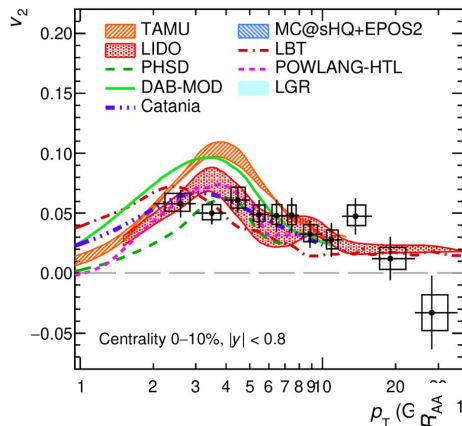
Proper description by TAMU, qualitative agreement for Catania and SHMc Explained by different effects of radial flow and coalescence on baryons and meson

- low momentum Heavy quarks (i.e. 3–4 GeV/c) mainly interact via elastic scatterings
- The typical momentum exchange in the interactions of Heavy quarks with the medium is small compared to the charm-quark mass. Therefore, Heavy quarks undergo Brownian motion in the medium characterised by many small-momentum kicks.
- the spatial diffusion coefficient  $D_s$ , which does not depend on the precise value of the Heavy quark mass and, hence, is a medium property. The diffusion coefficient is connected to the momentum transfer rate and the mean free path of the Heavy quarks.
- In particular, the TAMU [76], POWLANG-HTL [117,118], PHSD [125], and Catania [122,123] models describe the interactions of the charm quarks with the medium constituents solely via collisional processes, while the MC@sHQ+EPOS2 [115], DABMOD [116], LBT [119, 120], LGR [121], and LIDO [124] calculations include also radiative processes. All the models, except for DAB-MOD, include initial-state effects by using nuclear PDFs (nPDFs) in the calculation of the initial  $p_T$  distributions of charm quarks. A contribution of hadronization via quark recombination, in addition to charm-quark fragmentation, is included in all theoretical predictions.

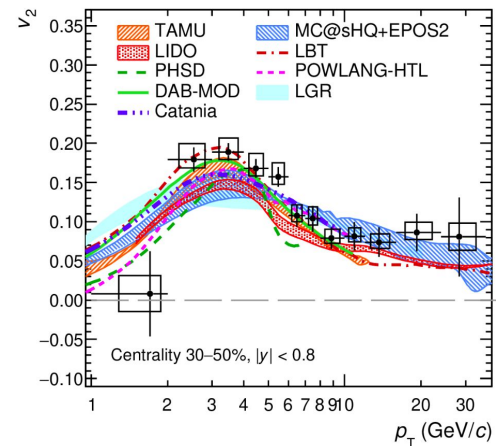
# Nuclear modification factor ( $R_{AA}$ )



LI-PUB-501952



LI-PUB-501956



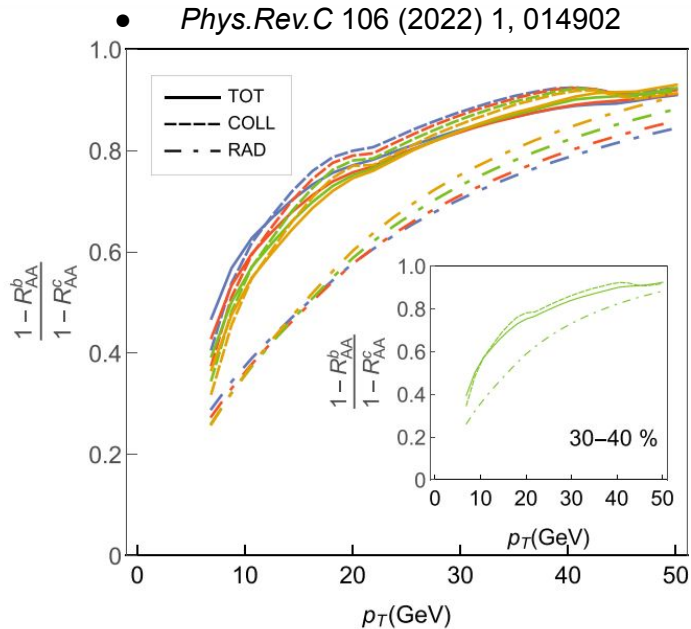


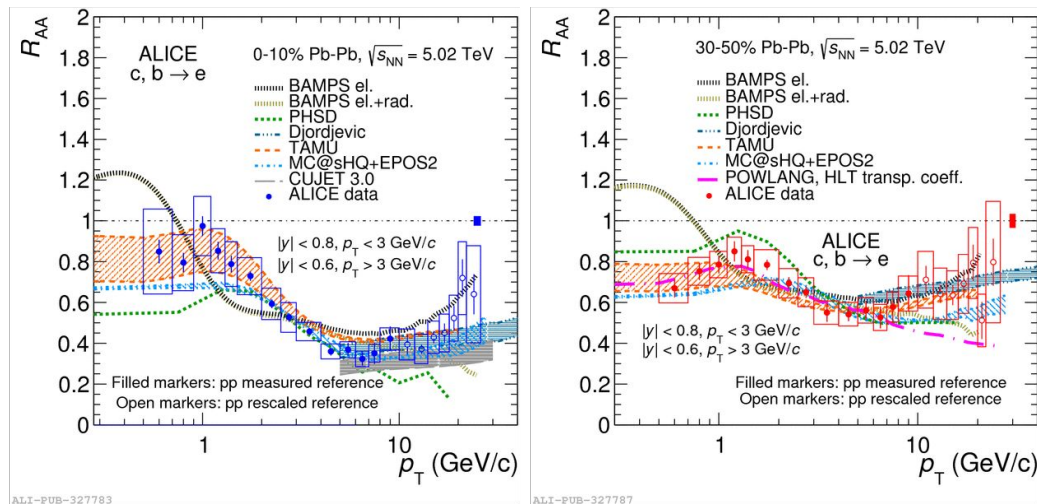
FIG. 2. Comparison of  $1 - R_{AA}$  bottom to charm ratios for *total*, *collisional*, and *radiative* suppressions, generated with the DREENA-C [35] framework. For clarity, 30–40% centrality is presented in the inset. Full, dashed, and dot-dashed curves denotes *total*, *collisional*, and *radiative* cases, respectively, as indicated in the legend. The blue, red, green, and orange curves correspond to 10–20%, 20–30%, 30–40%, and 40–50% centrality bins, respectively.



# Nuclear modification factor ( $R_{AA}$ )



PLB.2020.135377



$R_{AA}$  is compatible with the hypothesis of a partonic energy loss dependence on medium density  $\rightarrow$  path-length dependence

low  $p_T \rightarrow$  nuclear shadowing  $\rightarrow$   $\downarrow$  parton densities in nuclei at low  $x \rightarrow$  less Heavy quark production per binary collision in Pb–Pb with respect to the pp

hadrochemistry effects  $\rightarrow$  less production of HFe

Radial flow  $\rightarrow$  yield enhancement at intermediate  $p_T \sim 1$  in Pb–Pb

Models  $\rightarrow$  mass dependence of energy loss processes, transport dynamics, charm and beauty quark interactions with the QGP constituents, hadronisation mechanisms of Heavy quarks in the plasma, Heavy quark production cross section in nucleus–nucleus collisions

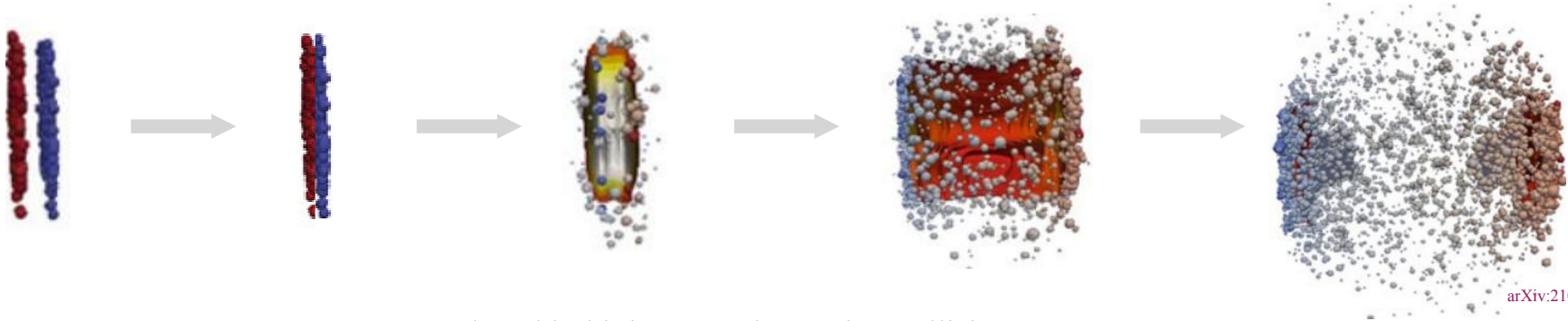
Most of the models provide a fair description of the data in the region  $p_T < 5$  GeV/c in both centrality classes, except for BAMPS

MC@sHQ+EPOS2, PHSD, TAMU, and POWLANG models include nuclear modification of the parton distribution functions  $\rightarrow$  necessary to predict the observed suppression of the RAA at low  $p_T$

Well described by the TAMU prediction at  $p_T < 3$  GeV/c within the uncertainties related to the shadowing effect on charm quarks  
Overestimate the  $R_{AA}$  for  $p_T > 3$  GeV/c, probably due to the missing implementation of the radiative energy loss in the model

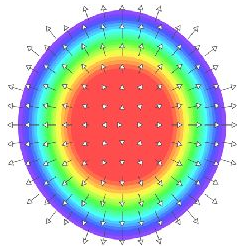
The CUJET3.0 and Djordjevic models provide a good description of the  $R_{AA}$  within the uncertainties in both centrality intervals for  $p_T > 5$  GeV/c, suggesting that the dependence of radiative energy loss on the path length in the medium

# Introduction

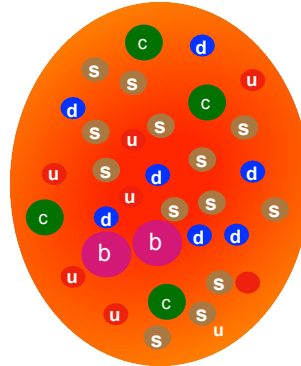


arXiv:2101.04963

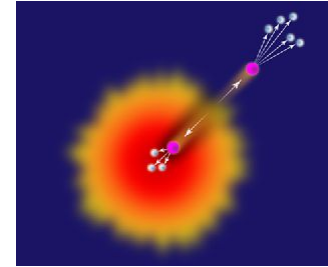
- **Quark Gluon Plasma (QGP)** produced in high energy heavy-ion collisions.
- Experimental evidence of QGP formation from light hadrons.



Collective flow



Enhanced strange quarks

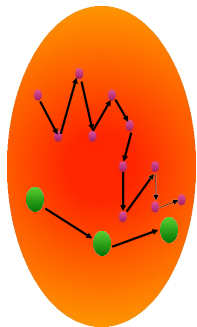


Jet quenching

# How to study heavy-flavours (HF)

- **Quarkonia**  $\rightarrow$   $J/\Psi$ ,  $\Psi(2S)$ ,  $Y(1S)$ ,... (bound states of Charm and Beauty quarks)
- **Open heavy-flavour**  $\rightarrow$  Heavy quark (c/b) hadronize with light quarks (q)

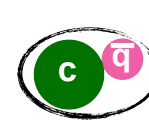
- D mesons ( $D^0$ ,  $D^+$ ,  $D_s$ ,  $D_s^*$ ), B meson ( $B^0$ ,  $B^+$ ,...),  $\Lambda_c$  baryon,  $\Lambda_b$  baryon



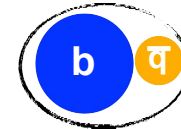
**Experimentally heavy-flavour hadrons studied through their decay products:**

- $c, b \rightarrow l(e, \mu) + X$  (Semi-leptonic decay channels)
- $D^0 \rightarrow K^- + \pi^+$  (Hadronic decay channels)

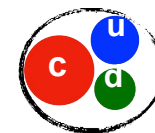
D meson



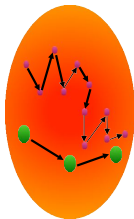
B meson



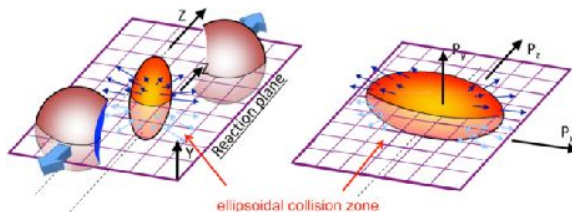
$\Lambda_c$  baryon



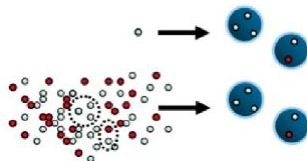
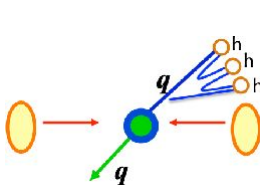
- **Nuclear Modification Factor ( $R_{AA}$ ):** energy loss in the QGP



- **Azimuthal anisotropy ( $v_n$ ):** information about the initial collision geometry and its fluctuations

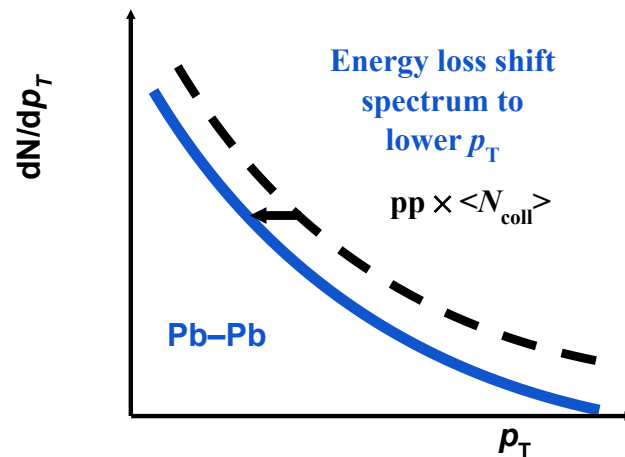
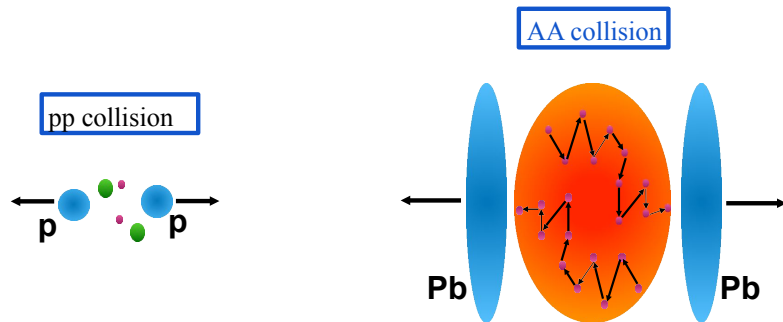


- **Jet fragmentation and hadronization processes**



# Nuclear Modification factor ( $R_{AA}$ )

Measuring energy loss: **Nuclear Modification Factor ( $R_{AA}$ )**



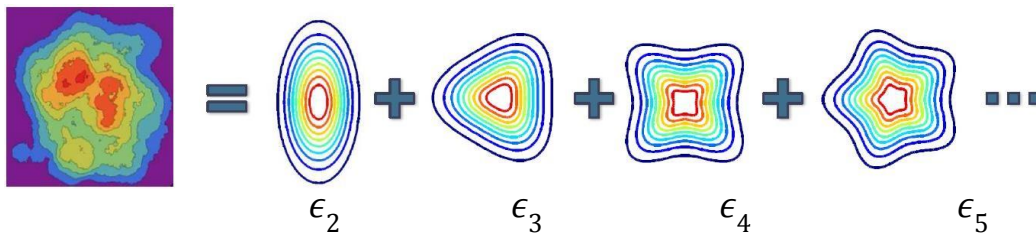
$$R_{XA} = \frac{1}{\langle N_{coll} \rangle} \frac{Y_{XA}}{Y_{pp}}$$

- $\langle N_{coll} \rangle$  Average number of binary nucleon-nucleon collisions
- $Y_{pp}$  Yield of a particle in proton-proton collisions
- $Y_{XA}$  Yield of a particle in heavy-ion collisions

$R_{XA} = 1 \rightarrow$  No modification  
 $R_{XA} < 1 \rightarrow$  Modification

- **Low  $p_T$ :** Elastic collision with medium constituents (diffusion Brownian motion, possible thermalisation in the medium)
- **High  $p_T$ :** Radiative energy loss (gluon emission)

- Volume of interacting matter initially **anisotropic in coordinate space**



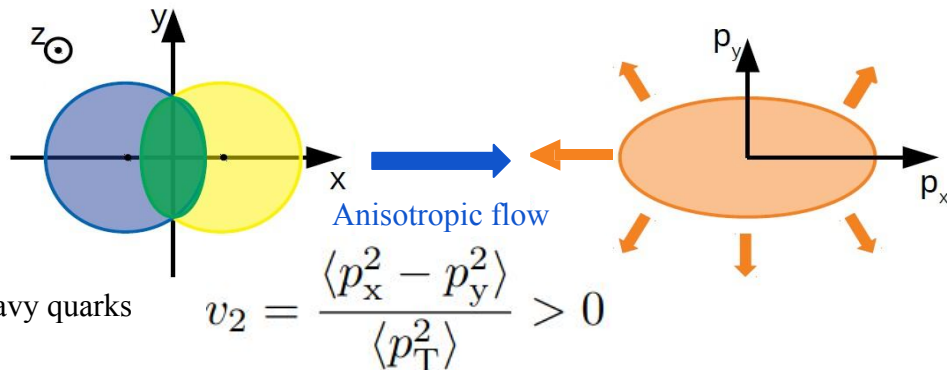
- Anisotropic flow:** Transfer of the **initial anisotropy** into **anisotropy in momentum space** via the thermalized medium
- Quantified via Fourier expansion

$$f(\varphi) = \frac{1}{2\pi} \left[ 1 + 2 \sum_{n=1}^{\infty} v_n \cos[n(\varphi - \Psi_n)] \right]$$

**Elliptic flow ( $v_2$ )**

**Low  $p_T$ :** participation in collective motion and thermalisation of Heavy quarks

**High  $p_T$ :** path-length dependence of energy loss

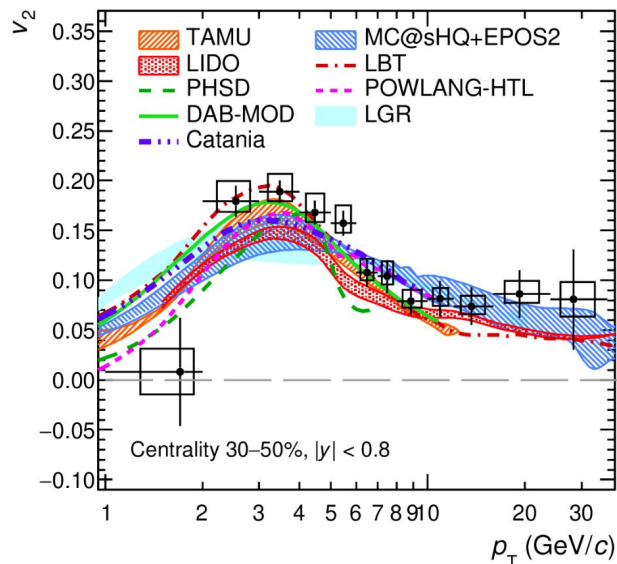
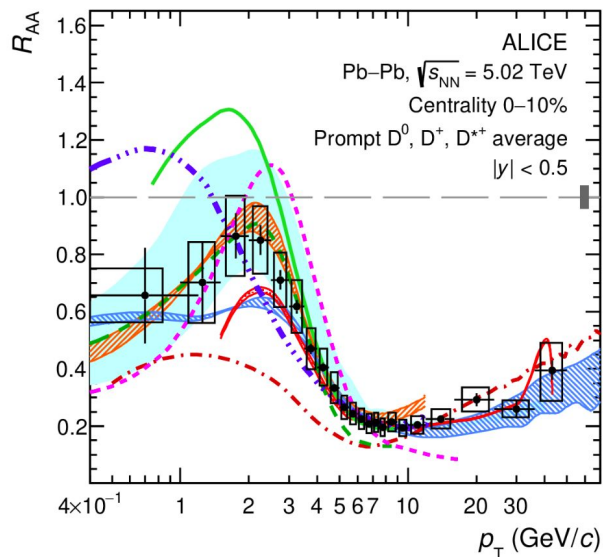




# Possibility of simultaneous description of $R_{AA}$ and $v_2$ ?



JHEP01(2022)174



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

- The low  $p_T$  region is sensitive not only to charm-quark interaction with the medium but also to
  - Initial-state effects (nPDFs)
  - Bulk evolution of the medium

ALI-PUB-501952

Simultaneous description of  $R_{AA}$  and  $v_2$  challenging for charm-quark transport models

- Charm-quark hadronization via **recombination** crucial to describe **low and intermediate  $p_T$** : D mesons acquire additional flow from charm-quark recombination with light quarks
- **Radiative energy loss** important to describe **intermediate and high  $p_T$**

# Study of open heavy-flavours with ALICE detector



## Time Projection Chamber ( $|\eta| < 0.9$ )

- Tracking
- PID via specific energy loss

## V0 detectors

- Triggering,
- Multiplicity estimator  
 $2.8 < \eta < 5.1$  (V0A)  
 $-3.7 < \eta < -1.7$  (V0C)

## Time-Of-Flight detector ( $|\eta| < 0.9$ )

- Tracking
- PID through time-of-flight

## Calorimeter (EMCal & DCal) ( $|\eta| < 0.7$ )

- Trigger
- PID via Energy measurement and shower shape

## Inner Tracking System ( $|\eta| < 0.9$ )

- Track reconstruction
- Primary and decay vertices reconstruction
- low momentum particle identification

## Muon spectrometer

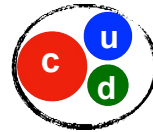
- Muon reconstruction  
 $-4.0 < \eta < -2.5$

**Open heavy-flavour**  $\rightarrow$  Heavy quark (c/b) hadronize with light quarks (q)

D meson



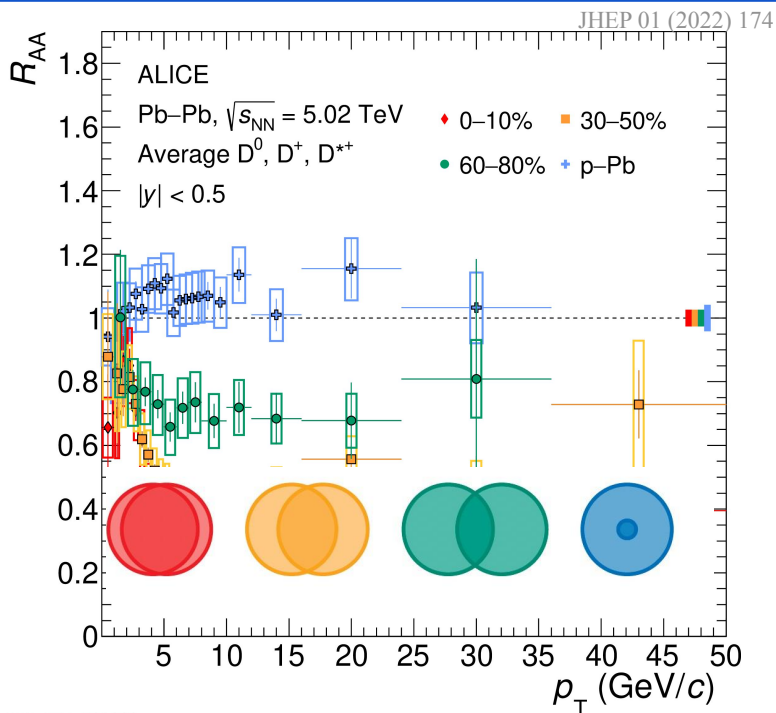
$\Lambda_c$  baryon



**Measured through their decay products:**

- $c, b \rightarrow l(e, \mu) + X$  (Semi-leptonic decay channels)
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# Nuclear modification factor ( $R_{AA}$ ) dependence on system size



Pb-Pb 60-80%: JHEP 10 (2021) 174  
p-Pb: JHEP 12 (2019) 092

$$R_{AA}(p_T) = \frac{1}{\langle T_{AA} \rangle} \frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T},$$

- $\langle T_{AA} \rangle \rightarrow$  average nuclear overlap function
- $d\sigma_{pp}/dp_T \rightarrow$  production cross section in proton-proton collisions
- $dN_{AA}/dp_T \rightarrow p_T$ -differential production yield in heavy-ion collisions

$R_{AA} = 1 \rightarrow$  No modification  
 $R_{AA} < 1 \rightarrow$  Energy-loss

Nuclear modification factor in different centrality classes in  
**Pb-Pb collisions (0-10%, 30-50%, 60-80%) + p-Pb collisions**

Suppression increasing with collision centrality

due to increasing density, size, and lifetime of the medium

Central

Semi  
central

Peripheral

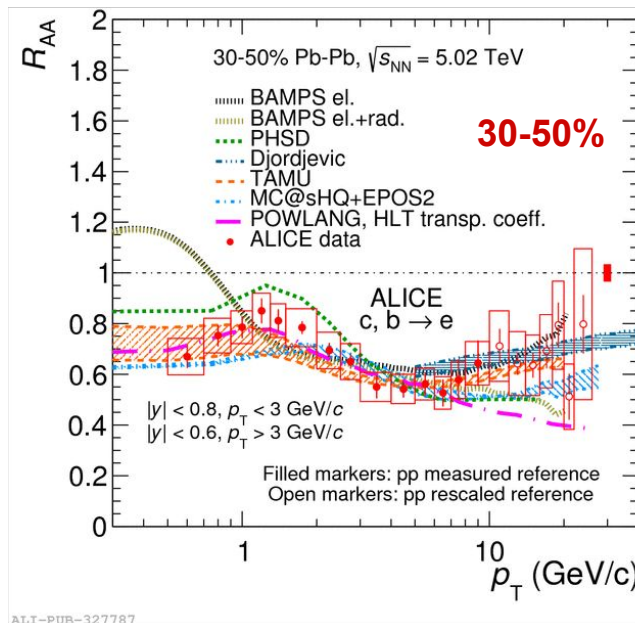
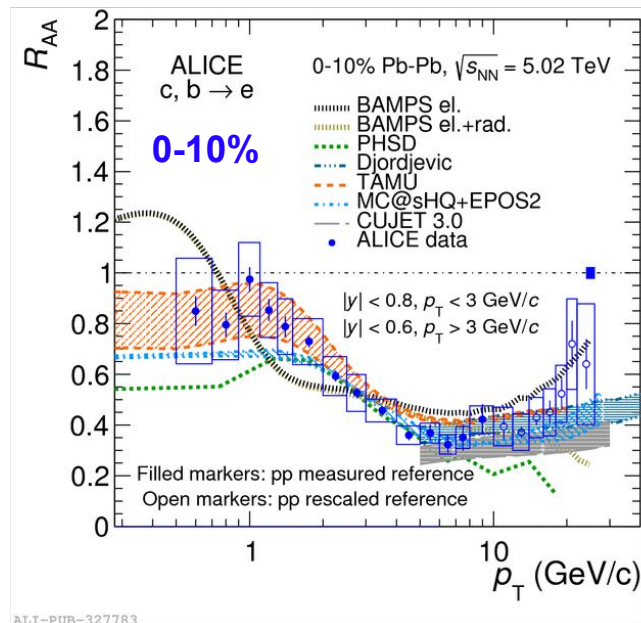
p-Pb

# Energy loss of HFe in the medium ( $R_{AA}$ )



PLB.2020.135377

HFe  $\rightarrow$  electrons from heavy-flavour hadron decay



**Models**  $\rightarrow$  mass dependence of energy loss, transport dynamics, charm and beauty quark interactions with the QGP constituents, hadronization mechanisms, Heavy quark production cross section

Most of the models provide a fair description of the data within uncertainty in both centrality classes, except for BAMPS

$R_{AA}$  is compatible with the hypothesis of a partonic energy loss dependence on medium density  $\rightarrow$  path-length dependence

- low  $p_T \rightarrow$  nuclear shadowing + collisional energy loss
- Hadrochemistry effects  $\rightarrow$  less production of HFe
- Radial flow  $\rightarrow$  yield enhancement at intermediate  $p_T \sim 1$  in Pb-Pb

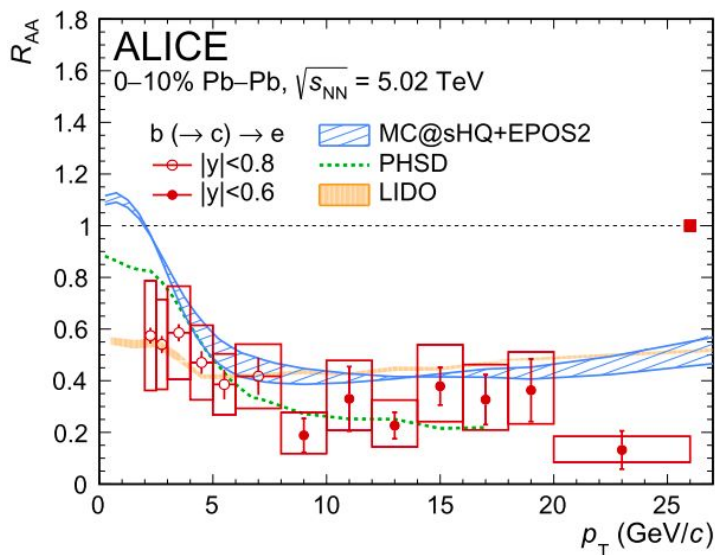
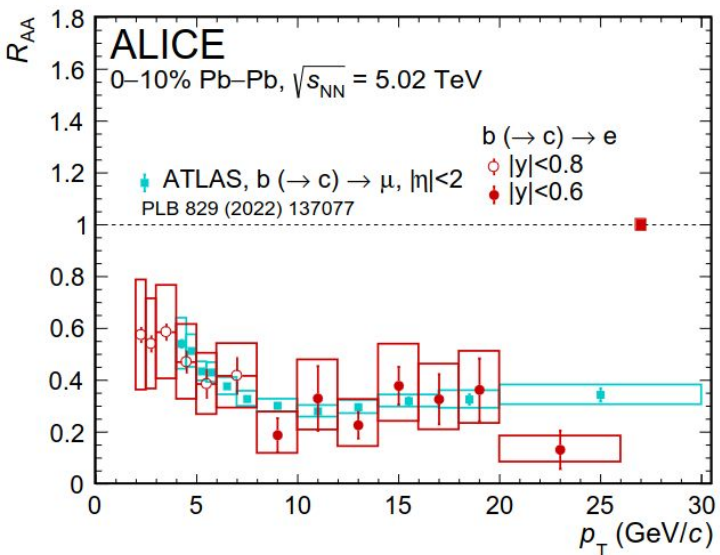
BAMPS: J.Phys.G 42 (2015) 11  
 Djordjevic: Phys.Rev.C 92 (2015) 2, 024918  
 TAMU: PRL 124, 042301 (2020)  
 PHSD: PRC 93, 034906 (2016)  
 POWLANG: EPJC 75, 121 (2015)  
 MC@sHQ+EPOS: PRC 91, 014904 (2015)

# Energy loss of beauty-decay electrons in the medium ( $R_{AA}$ )



ArXiv:2211.13985

$b \rightarrow c \rightarrow e \rightarrow$  electrons from beauty hadron decay



- **Nuclear shadowing**  
→ Suppression of yield at low  $p_T$
- **Hadrochemistry effects** → less production of HFe
- **Radial flow** → yield enhancement at intermediate  $p_T \sim 1$  in Pb–Pb

- **ALICE**  $R_{AA}(b \rightarrow c \rightarrow e) \approx$  **ATLAS**  $R_{AA}(b \rightarrow c \rightarrow \mu)$  → **no dependency on decay channels**
- **All models provide good description of data within uncertainty**