D meson measurements with ALICE

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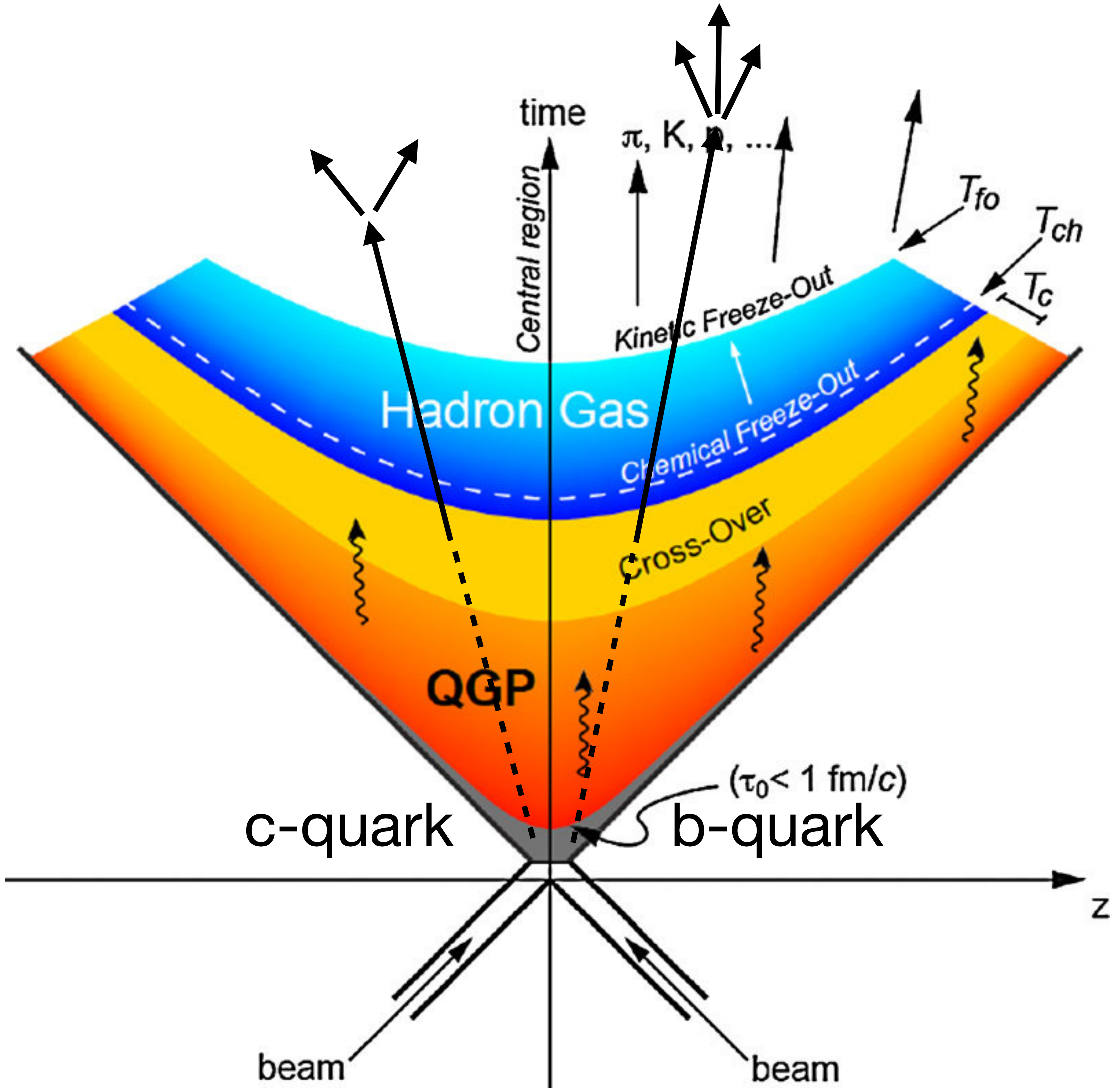
Heavy quarks in heavy ion collisions

Heavy quarks (charm and beauty):

excellent probes to investigate the QGP properties

- Produced at early stage of the collision before the QGP creation ($T_b < T_c < T_{QGP}$ ~ 0.3 fm/c)
- Experience the full system evolution

Phys. Rev. C 89, 034906



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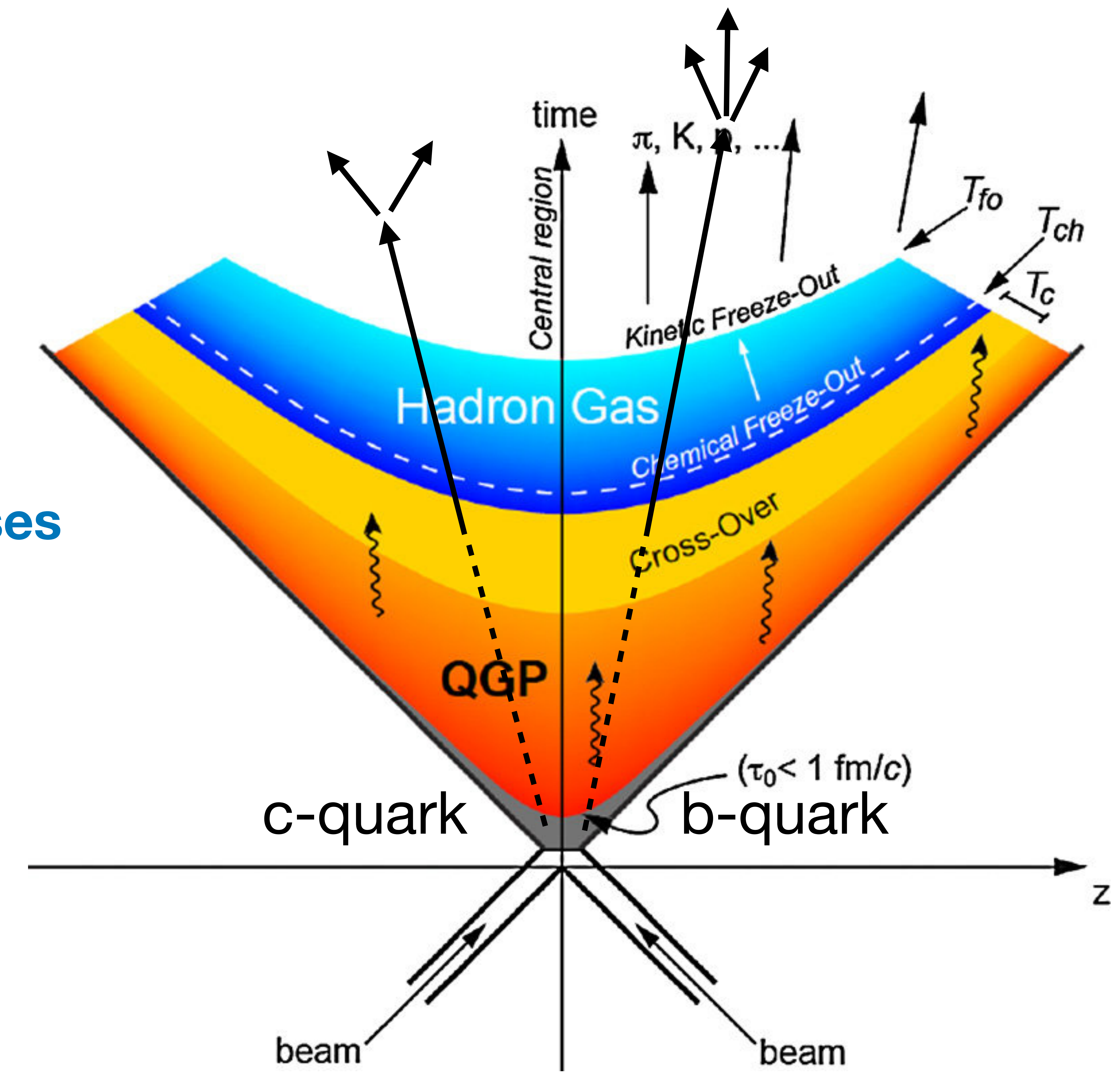


Interaction with the medium constituents

➡ Energy loss via **elastic collisions** and **radiative processes**

- nuclear modification factor R_{AA}

$$R_{AA}(p_T) = \frac{1}{< N_{coll}^{AA} >} \frac{dN_{AA}/(dy dp_T)}{dN_{pp}/(dy dp_T)}$$

QCD medium

QCD vacuum

➡ Participation in the fireball **collective motion**

- flow coefficients v_n

$$v_n = \langle \cos[n(\varphi - \Psi_n)] \rangle$$

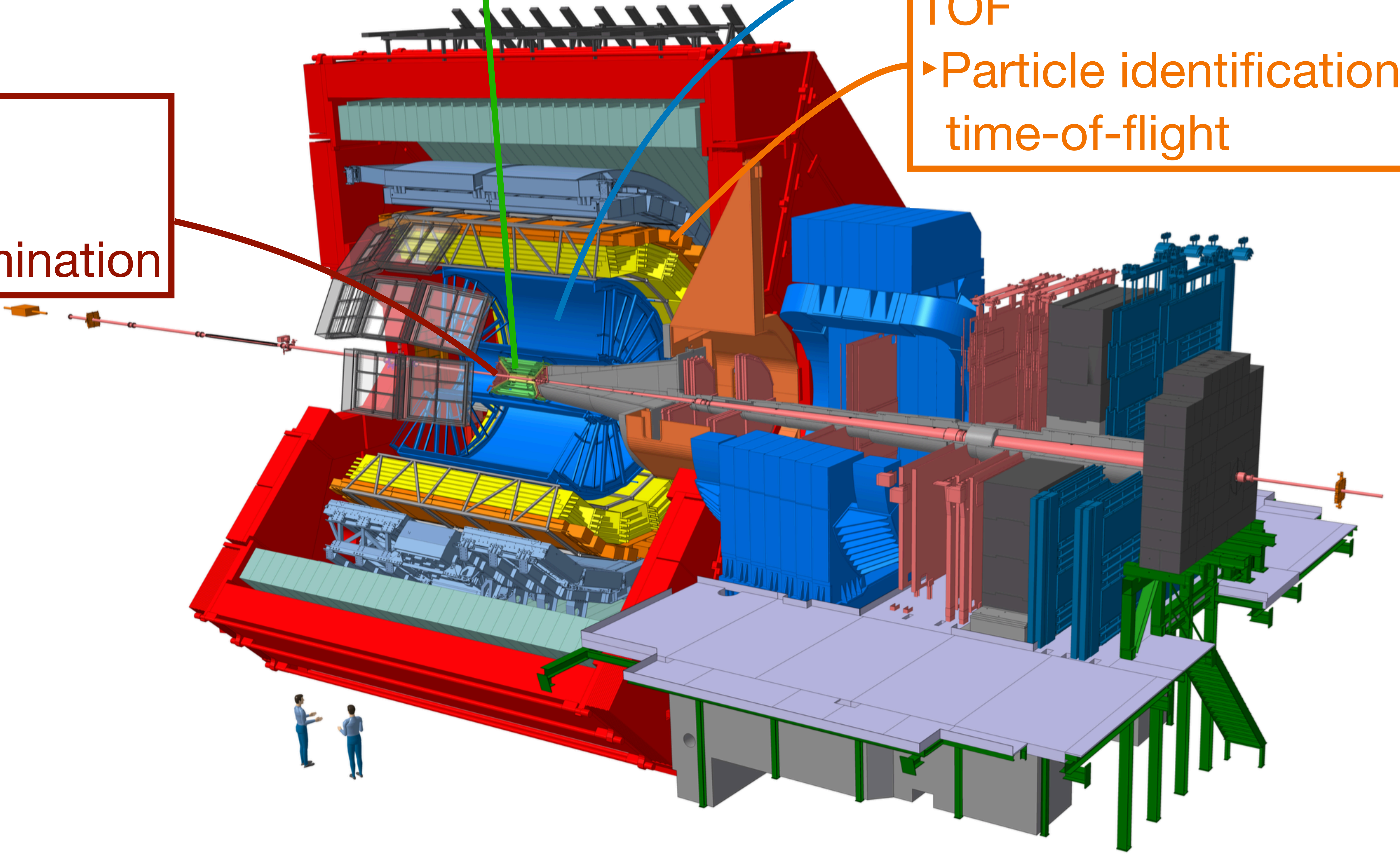
➡ Modification of the **hadronisation mechanism**

- colaescence/recombination with quarks from the medium
- sensitive to different meson and baryon species

A Large Ion Collider Experiment

D meson measurements conducted in the central barrel ($|\eta| < 0.5$), using:

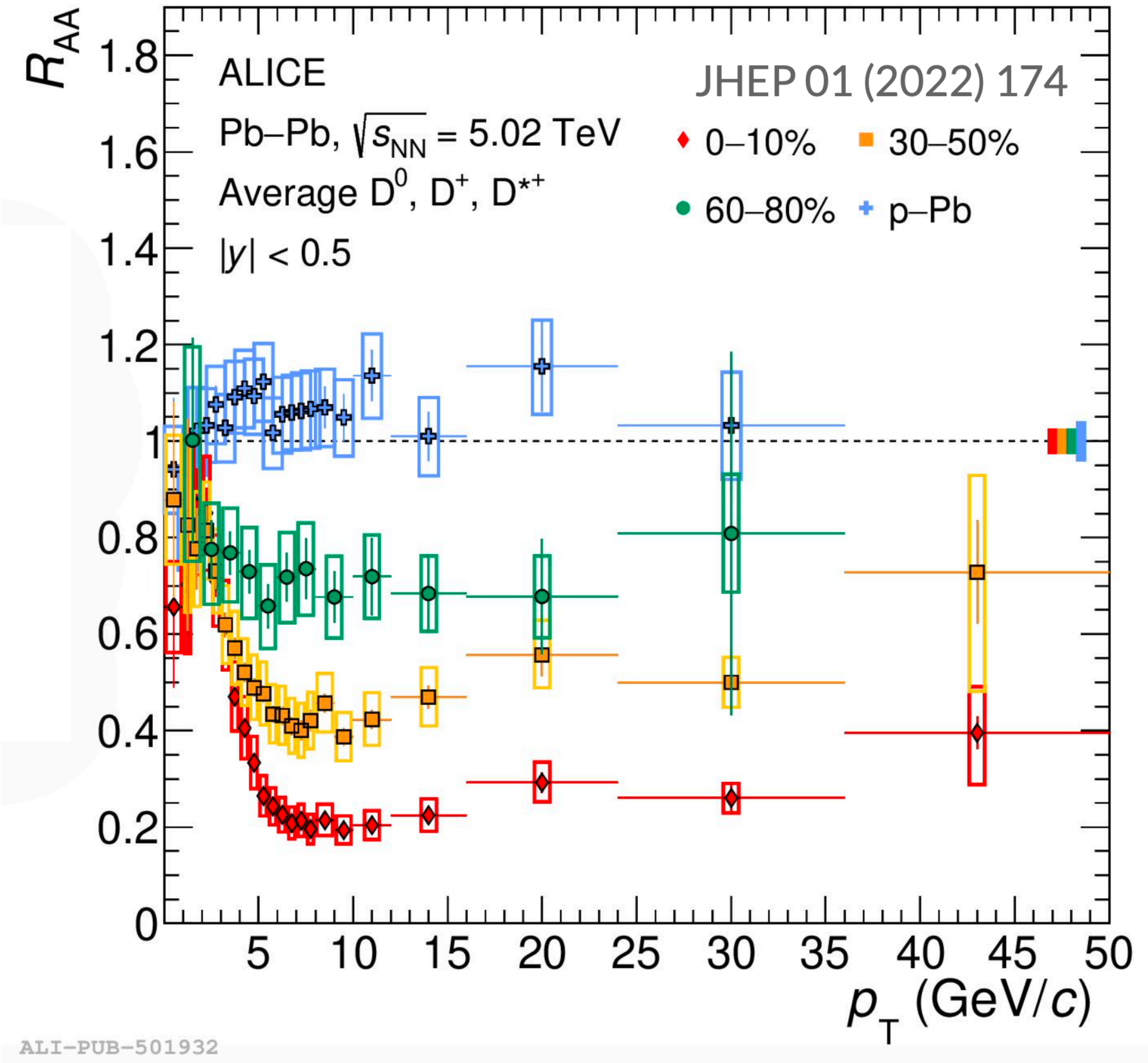
- Inner Tracking System
- Time Projection Chamber
- Time-of-Flight detector
- V0 detectors



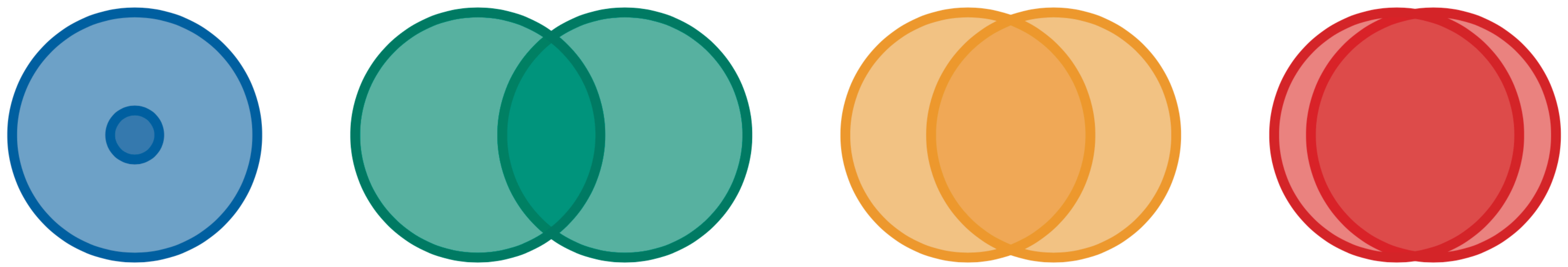
D meson measurements in this talk:

- $D^0(c\bar{u}) \to K^-\pi^+$
- $D^+(c\bar{d}) \to K^-\pi^+\pi^+$
- $D_s^+(c\bar{s}) \to \phi\pi^+ \to K^+K^-\pi^+$
- $D^{*+}(c\bar{d}) \to D^0\pi^+ \to K^-\pi^+\pi^+$

Charm quark energy loss

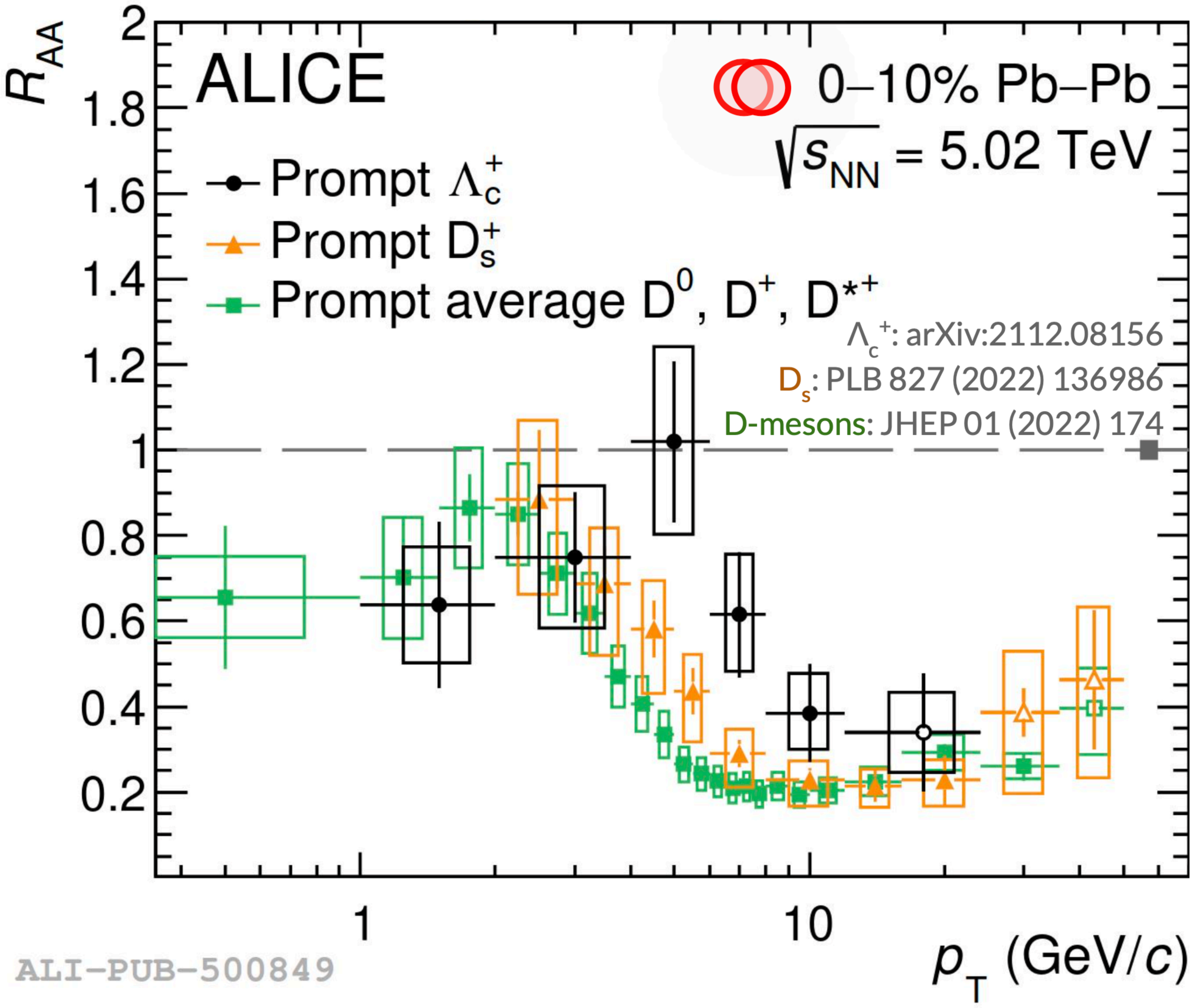


- **Suppression increases** from peripheral to central collisions (for $p_T > 3$ GeV/c)
  - ➡ Due to **increasing density**, **size** and **lifetime** of the **medium**



- **Clear p_T dependence:** suppression more pronounced from intermediate to high p_T

Charm quark energy loss

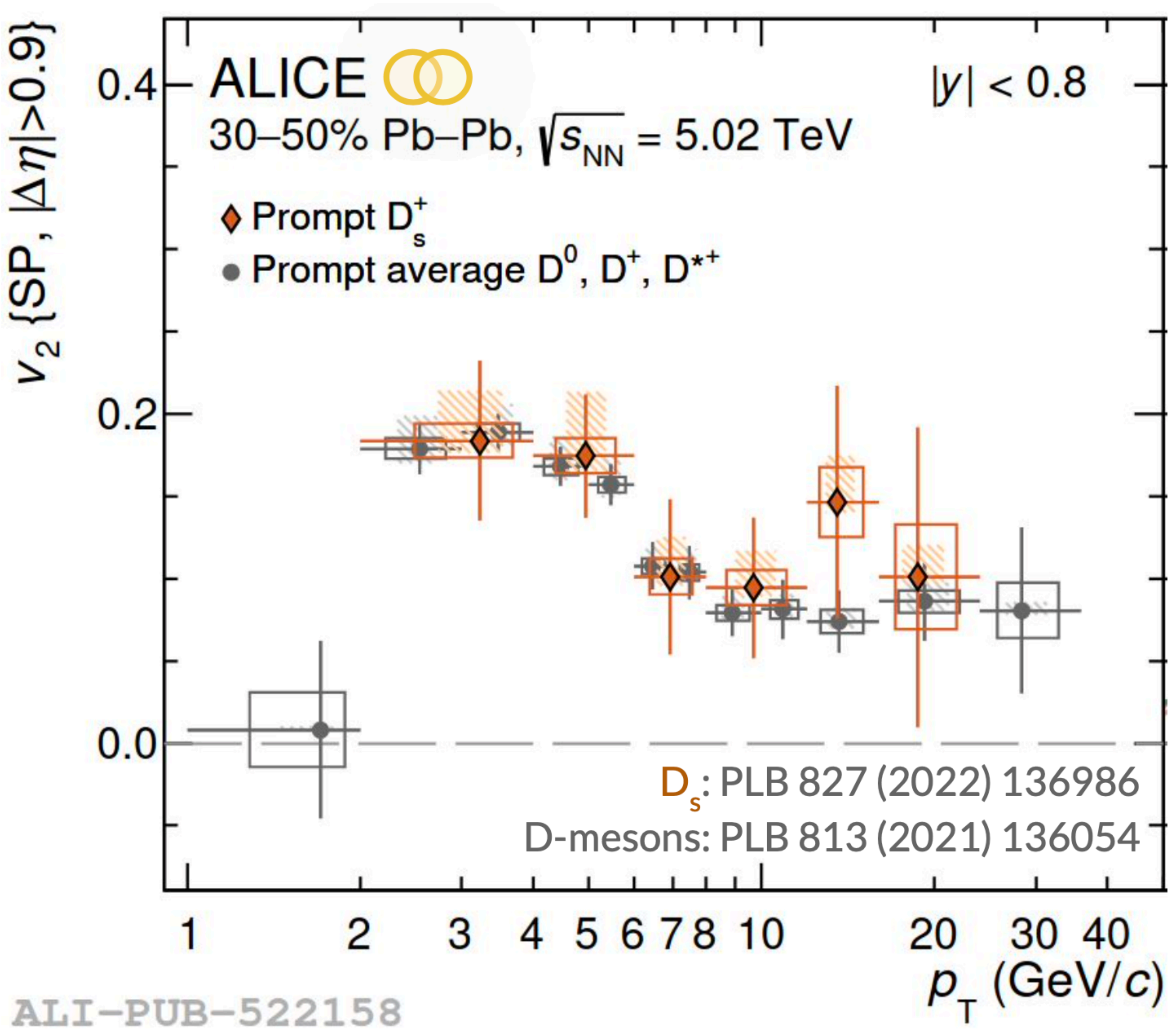


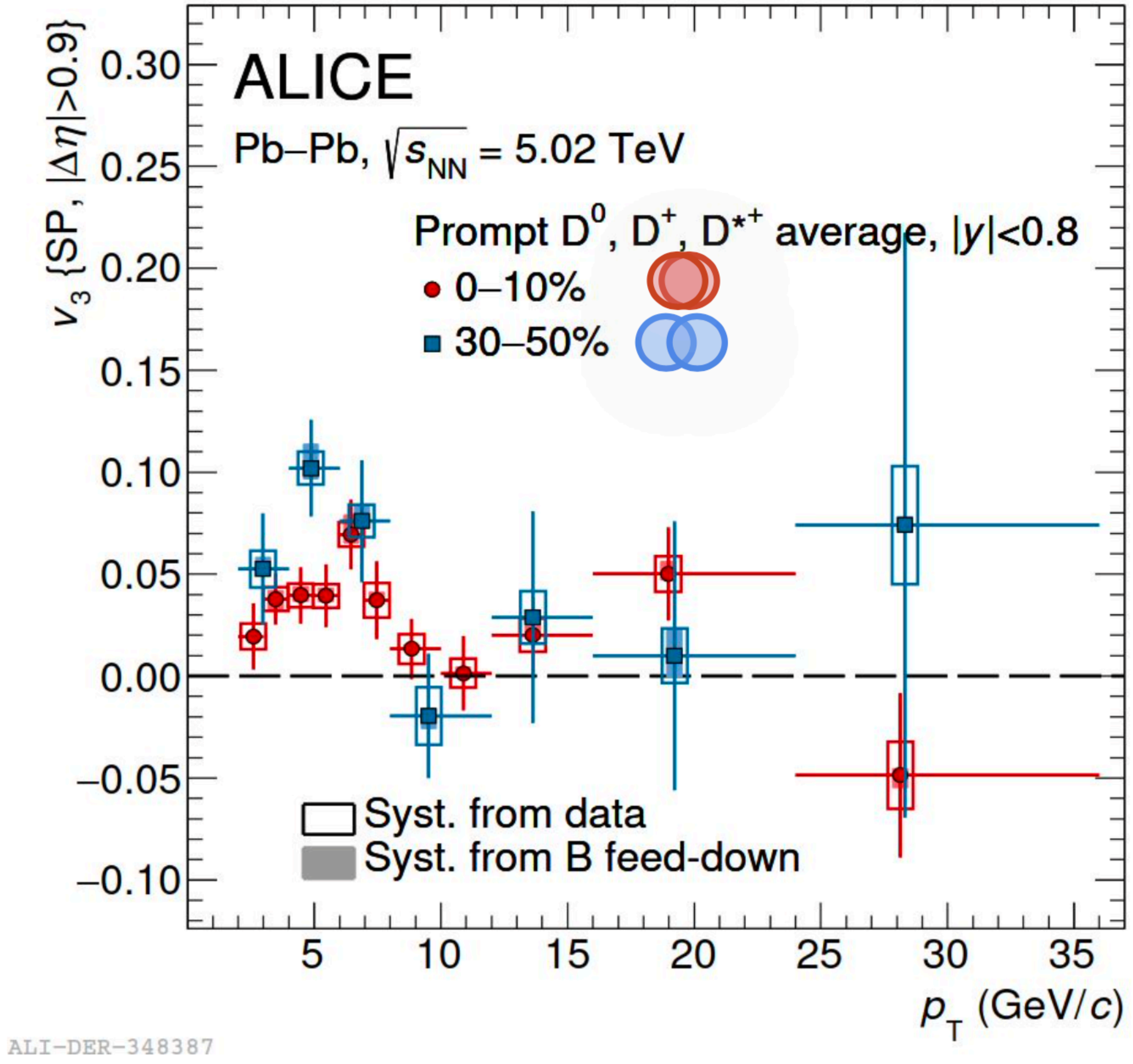
- Hint of hierarchy:
  $R_{AA}(\Lambda_c^+) > R_{AA}(D_s^+) > R_{AA}(D)$ for pT > 4 GeV/c in most central collisions

➡ **Modified hadronisation** mechanism?

➡ Interplay of **radial flow?**

Azimuthal anisotropies

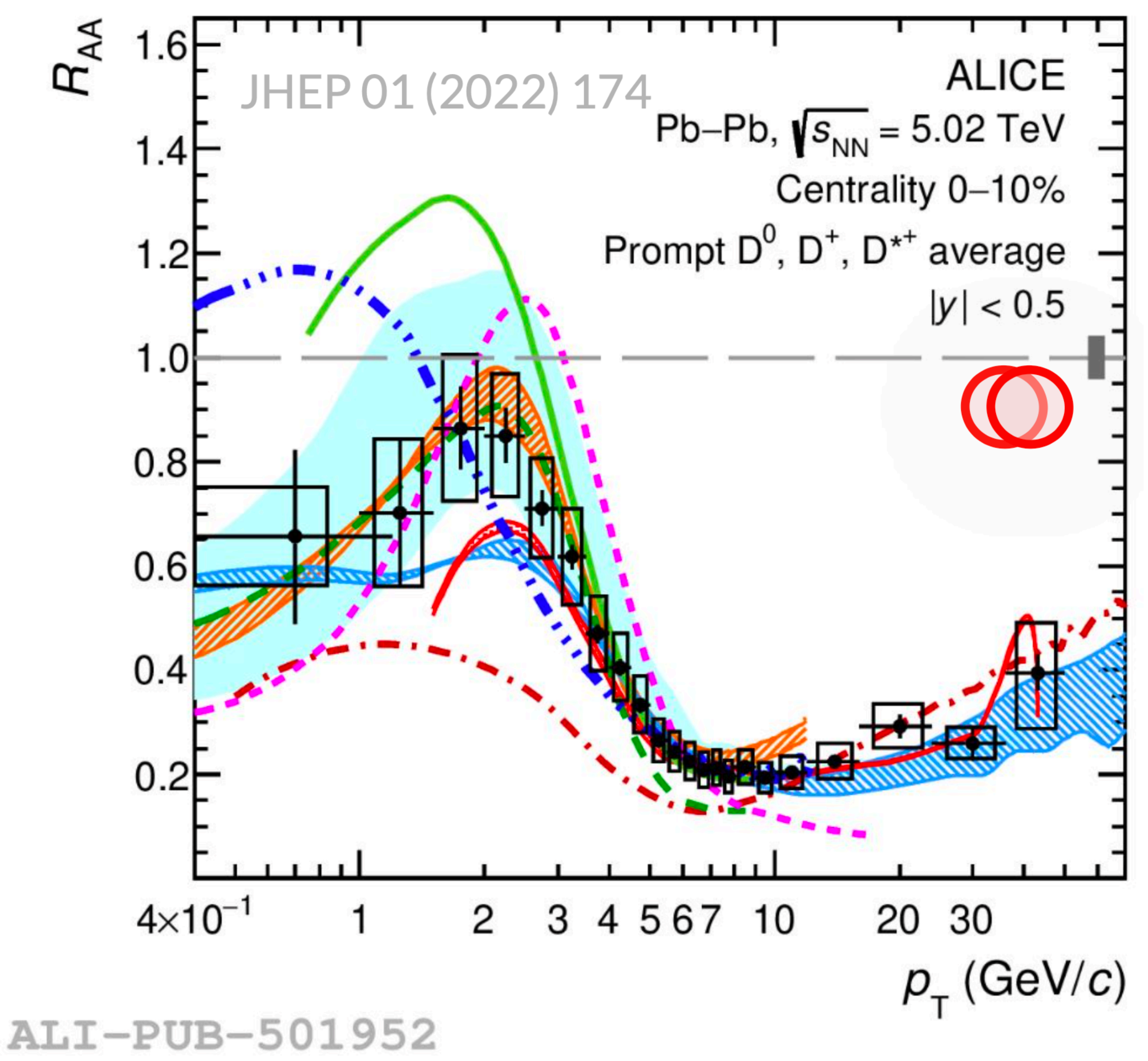


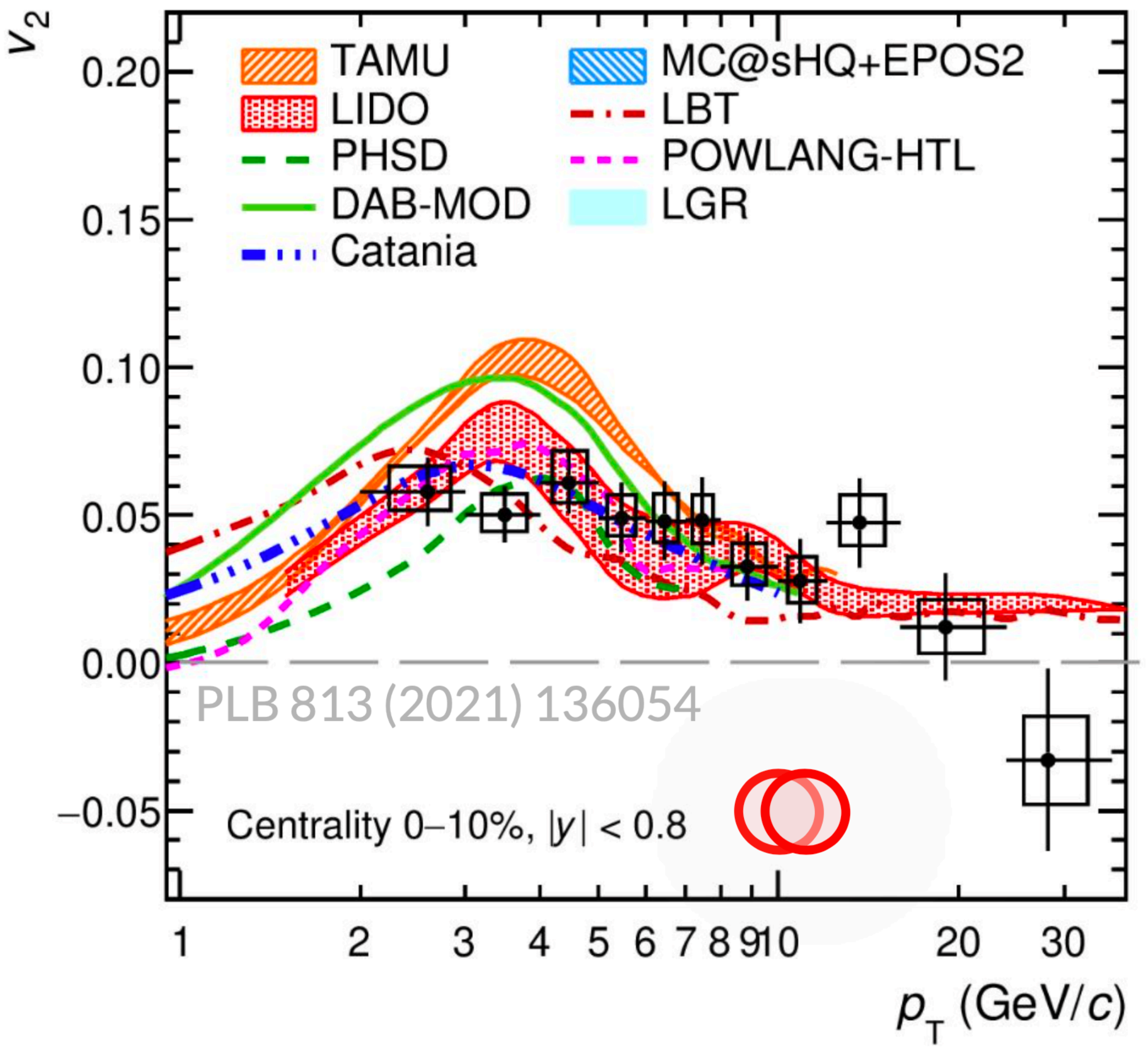


- Significant D meson elliptic (v_2) and triangular (v_3) flow for charm
  - ➡ charm-quark participation in QGP collective motion
  - ➡ D_s^+ elliptic flow in agreement with non-strange D-meson v_2 given current uncertainties

Charm quark transport

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





- **Constrain diffusion coefficient D_s** comparing R_{AA} and v_2 simultaneously

➡ Challenging for transport models

Charm quark transport

ALICE

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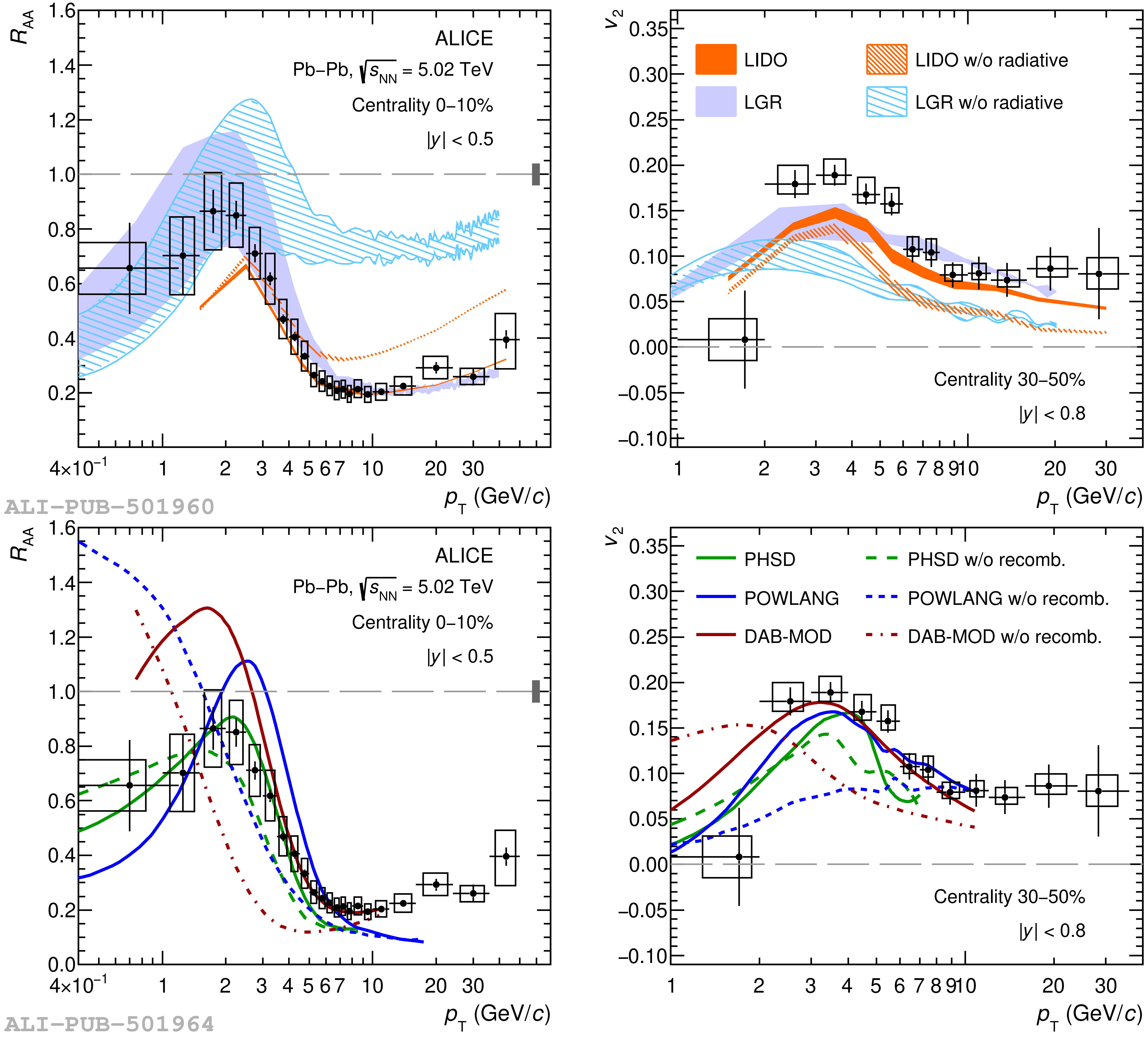
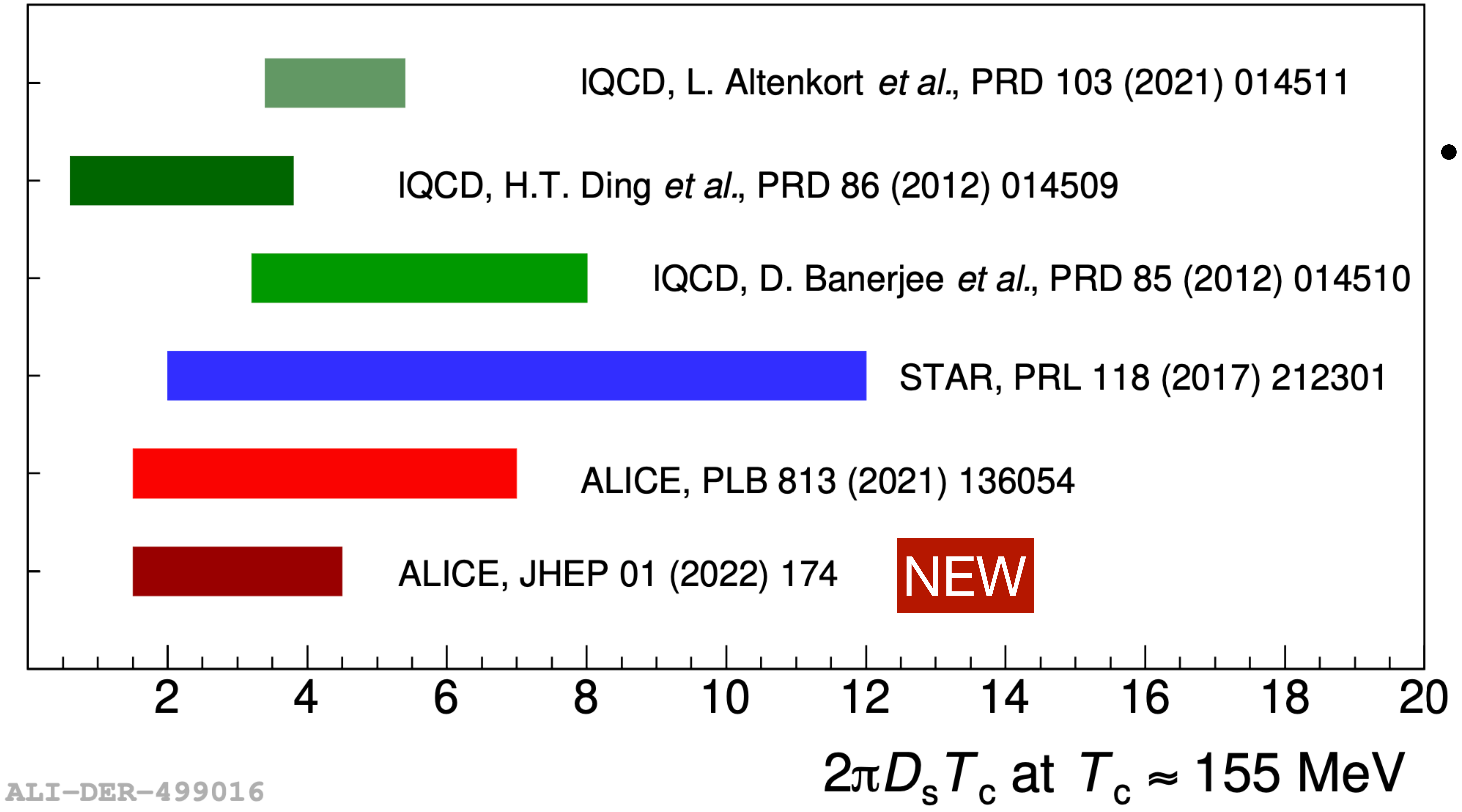


- **Constrain diffusion coefficient D_s** comparing R_{AA} and v_2 simultaneously
  - ➡ Challenging for transport models

- Deeper insight on differential comparsions
  - **Collisional energy loss** dominant at low p_T
  - **Radiative energy loss** dominant at intermediate and high p_T
  - **Fragmentation + recombination** is important to describe low and intermediate p_T

Charm quark transport

- **Spatial diffusion coefficient D_s** constrained from model-to-data comparison (χ^2 analysis) for both the R_{AA} and v_2



- TAMU, MC@sHQ, LIDO, LGR and Catania provide reasonable description

- $1.5 < 2\pi D_s(T) < 4.5$ corresponds to

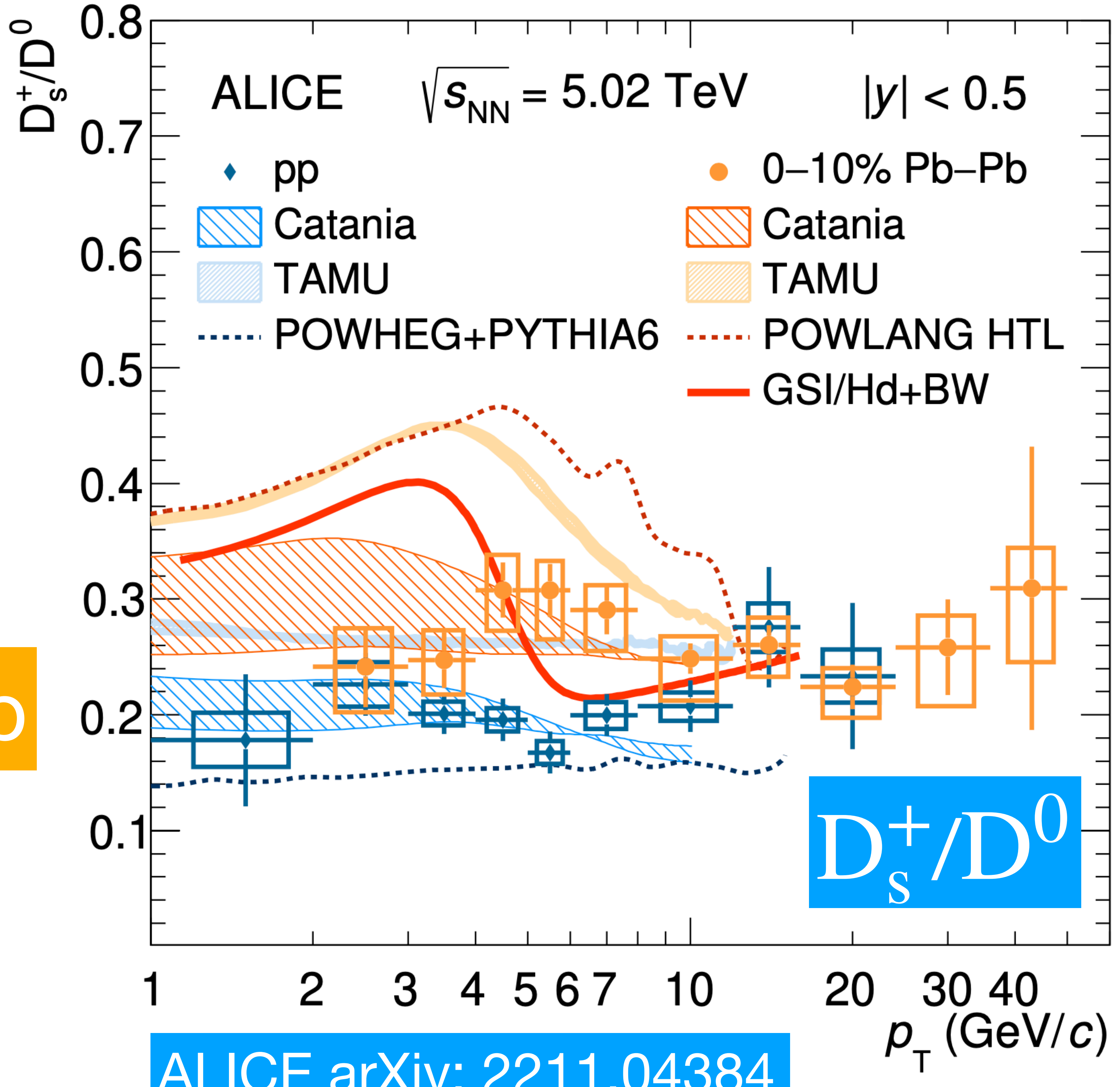
  $\tau_{charm} = (m_{charm} / T)D_s(T) \approx$ 3-8 fm/c $< \tau_{QGP\ lifetime} \approx$ 10 fm/c

  ➡ Charm thermalisation happens within the QGP lifetime

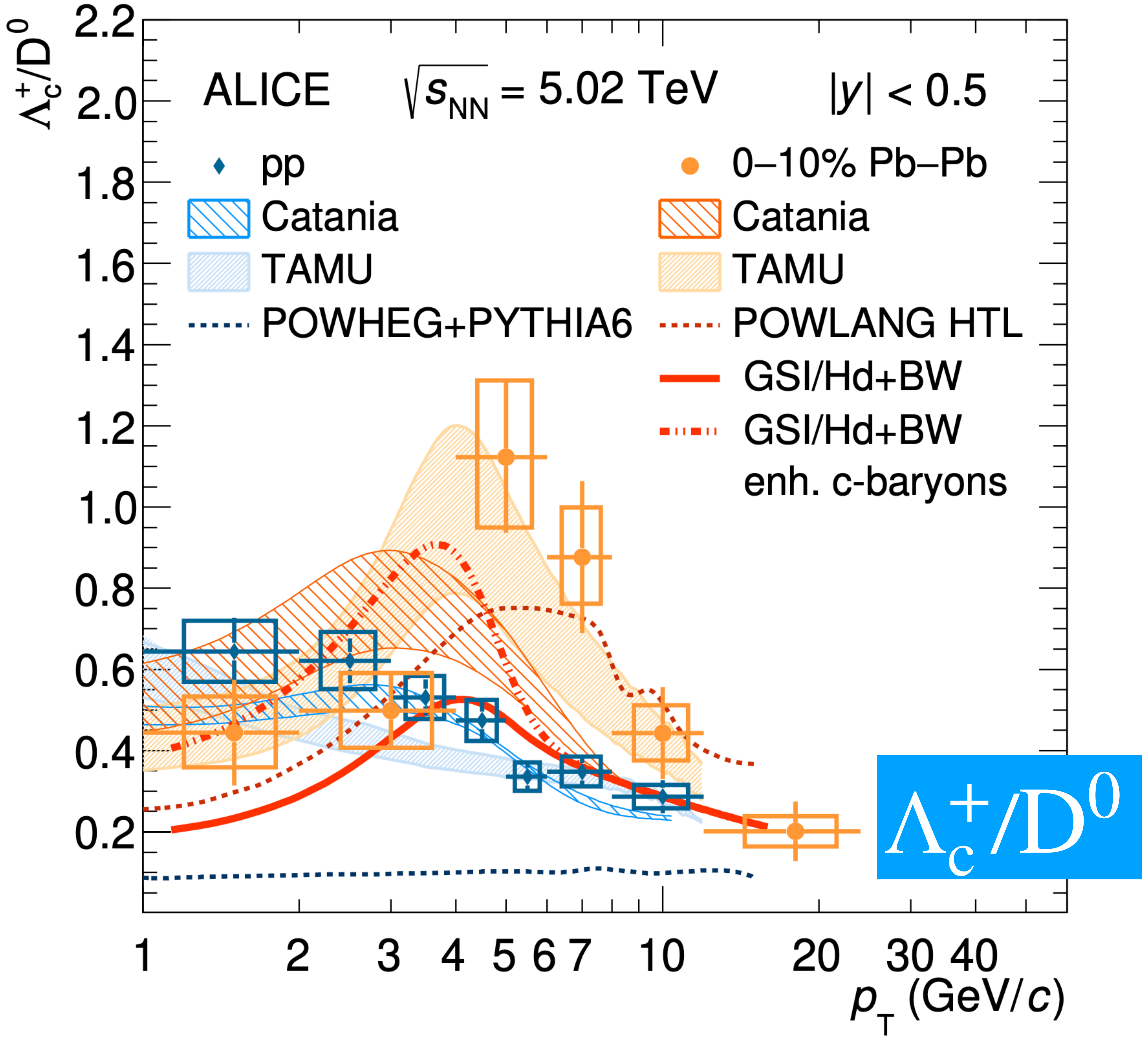
Charm quark hadronisation

pp

Pb–Pb



ALICE arXiv: 2211.04384

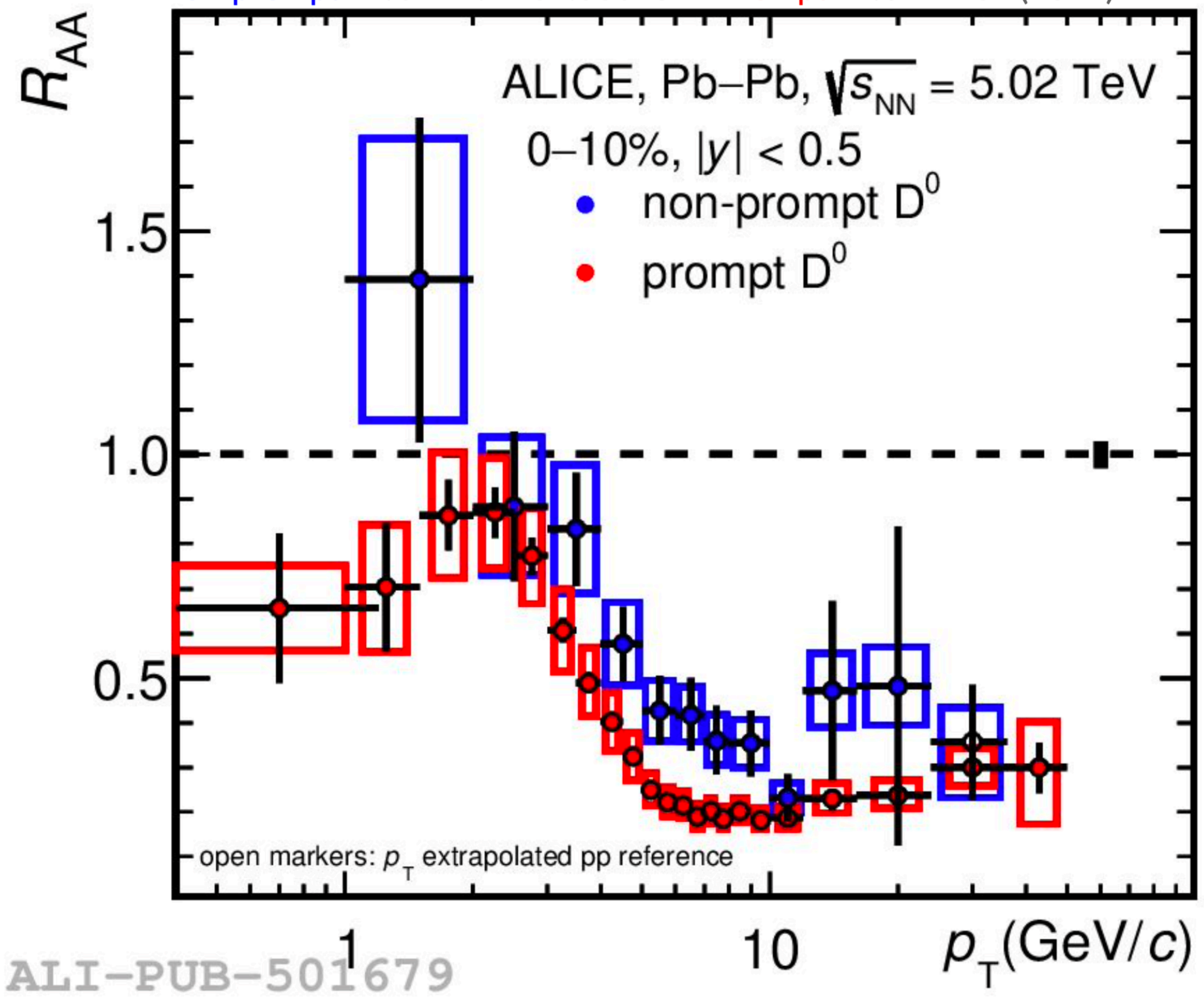


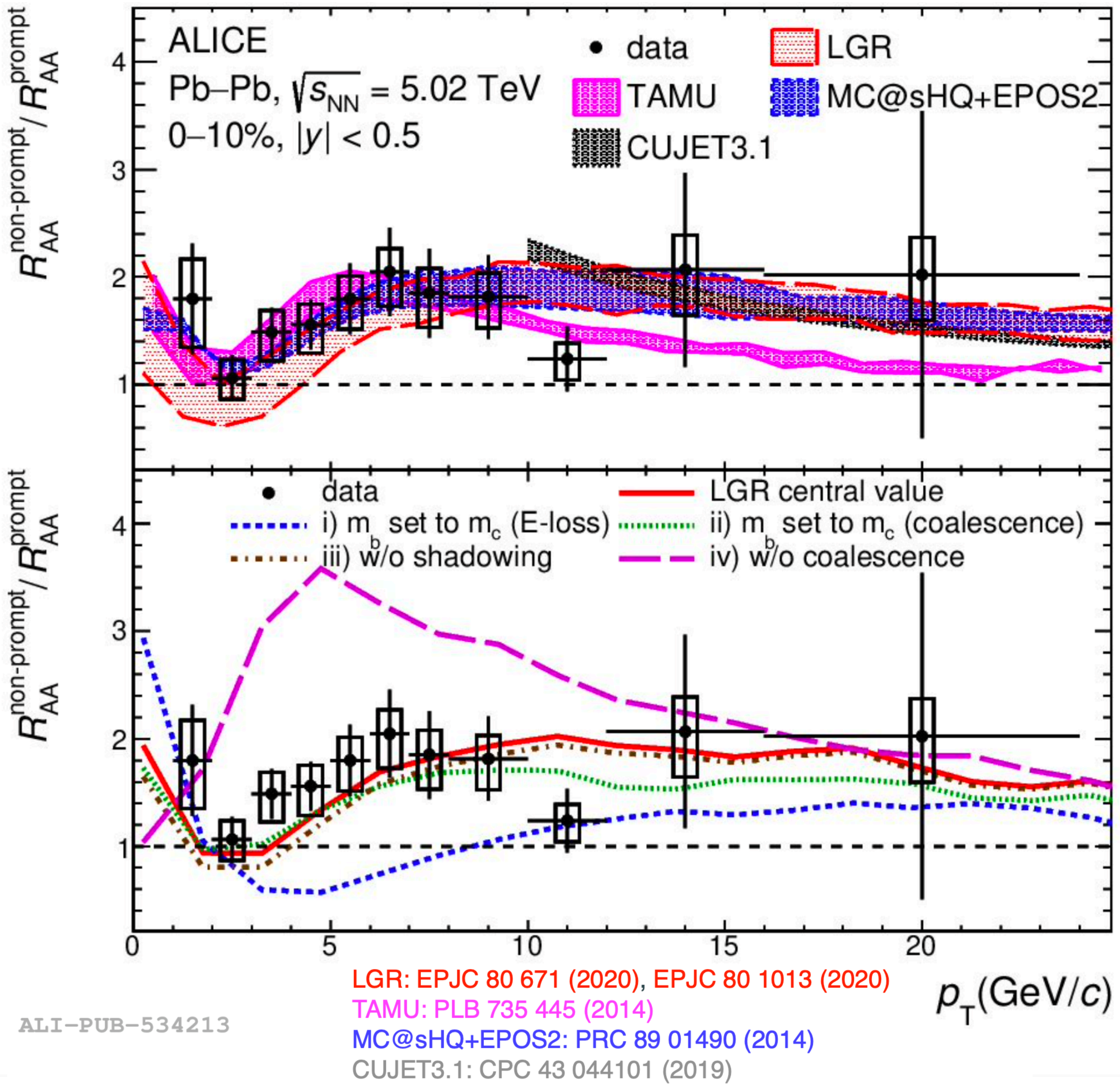
- D_s^+/D^0 enhancement at intermediate p_T in Pb–Pb w.r.t pp
  - ➡ Reasonably described by models including strangeness enhancement and **fragmentation + recombination**

- Λ_c^+/D^0 enhancement in Pb–Pb w.r.t pp in $4 < p_T < 8$ GeV/c
  - ➡ Different redistribution of p_T between baryons and mesons?

Extending to beauty sector: non-prompt D^0

Non-prompt D^0: arXiv: 2202.00815 Prompt D^0: JHEP 01 (2022) 174

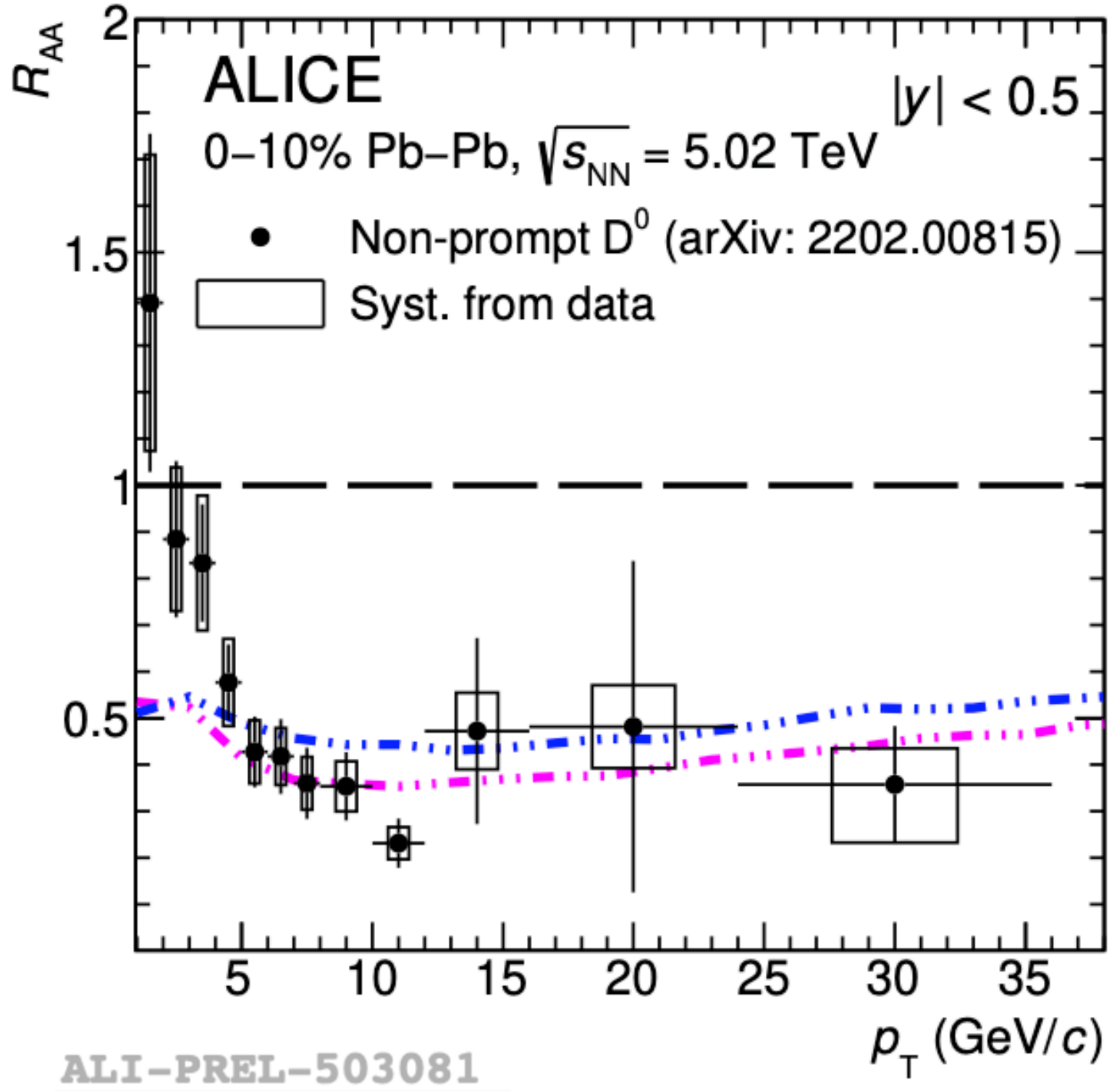


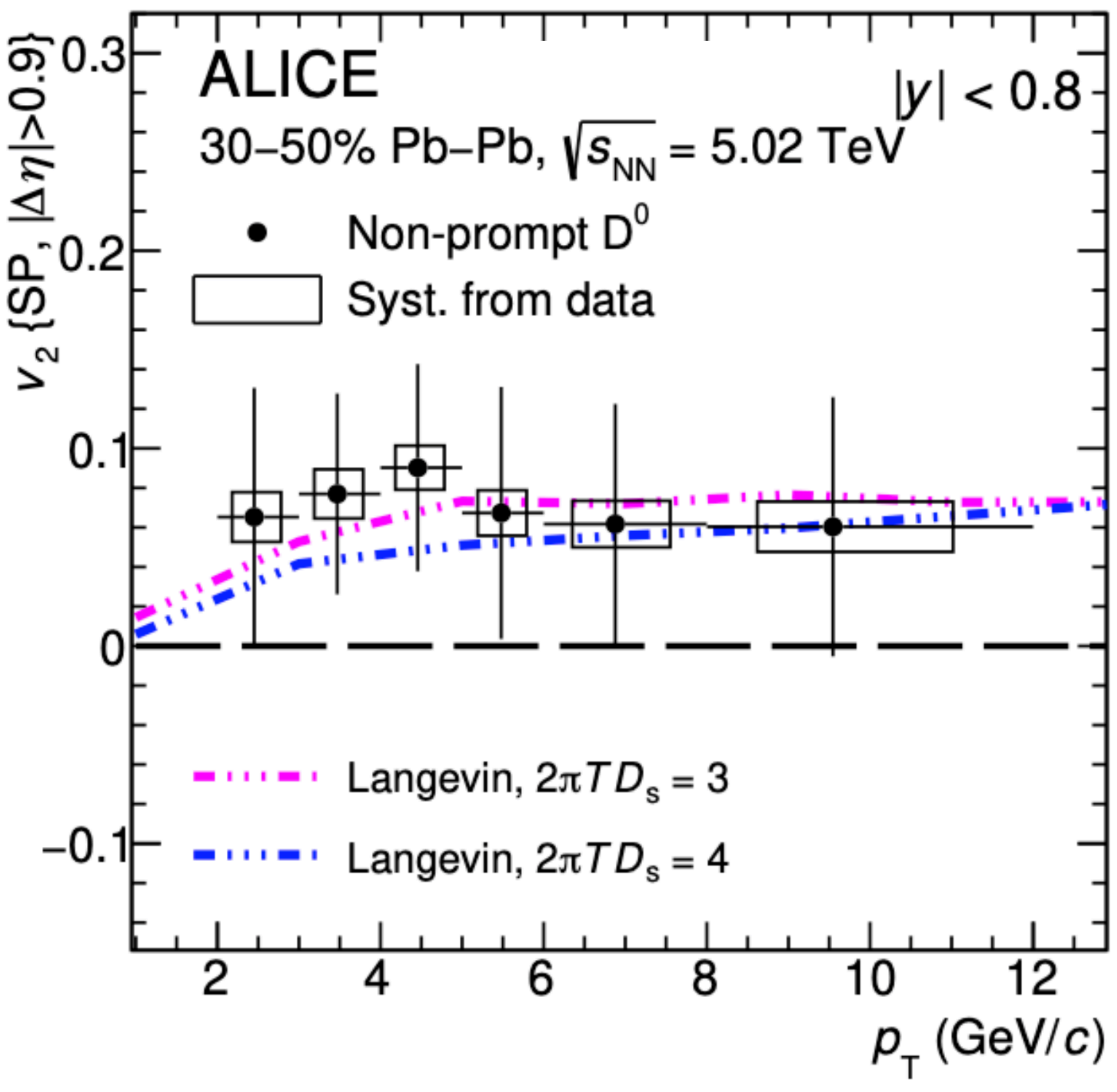


- Direct B measurements not accessible in Run 2
  - ➡ Beauty study via non-prompt D meson from b quark
- Hint of R_{AA}(beauty hadron) > R_{AA}(charm hadron)
  - ➡ Beauty quarks lose less energy than charm quarks
  - ➡ Mass dependence of in-medium energy loss

- Further insight from testing different **LGR** model configurations (default: **collisional+radiative energy loss**, hadronisation via **fragmentation+coalescence**)
  - ➡ **Prompt D^0 hadronisation via coalescence** explains the minimum at 2-3 GeV/c
  - ➡ Ratio close to unity if using m_{charm} for b quarks E-loss calculation —> **mass dependent** quark in-medium energy loss

Beauty quark transport





- Rough calculation of D_s in beauty sector is similar to that in charm sector ($2\pi D_s \approx 1.5$-4.5 for charm)
  - ➡ Indicating $\tau_{beauty} \propto m_{beauty} D_s \gtrsim \tau_{QGP\ lifetime}$ ($m_{beauty} \approx 3 m_{charm}$)
  - ➡ Different thermalisation of beauty than charm?
  - ➡ More precise measurements needed

Summary

- Heavy quarks undergo **energy loss in the medium (mass dependent)**
- Measurements described by models including **collisional and radiative energy loss**
- Heavy quarks **hadronise via fragmentation + coalescence**
- **Different degree of thermalisation between charm and beauty quarks**

- **Next step**? **Run 3**!