Recent highlights on heavy-flavor physics in heavy-ion collisions

Focus on the LHC

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中国物理学会高能物理分会

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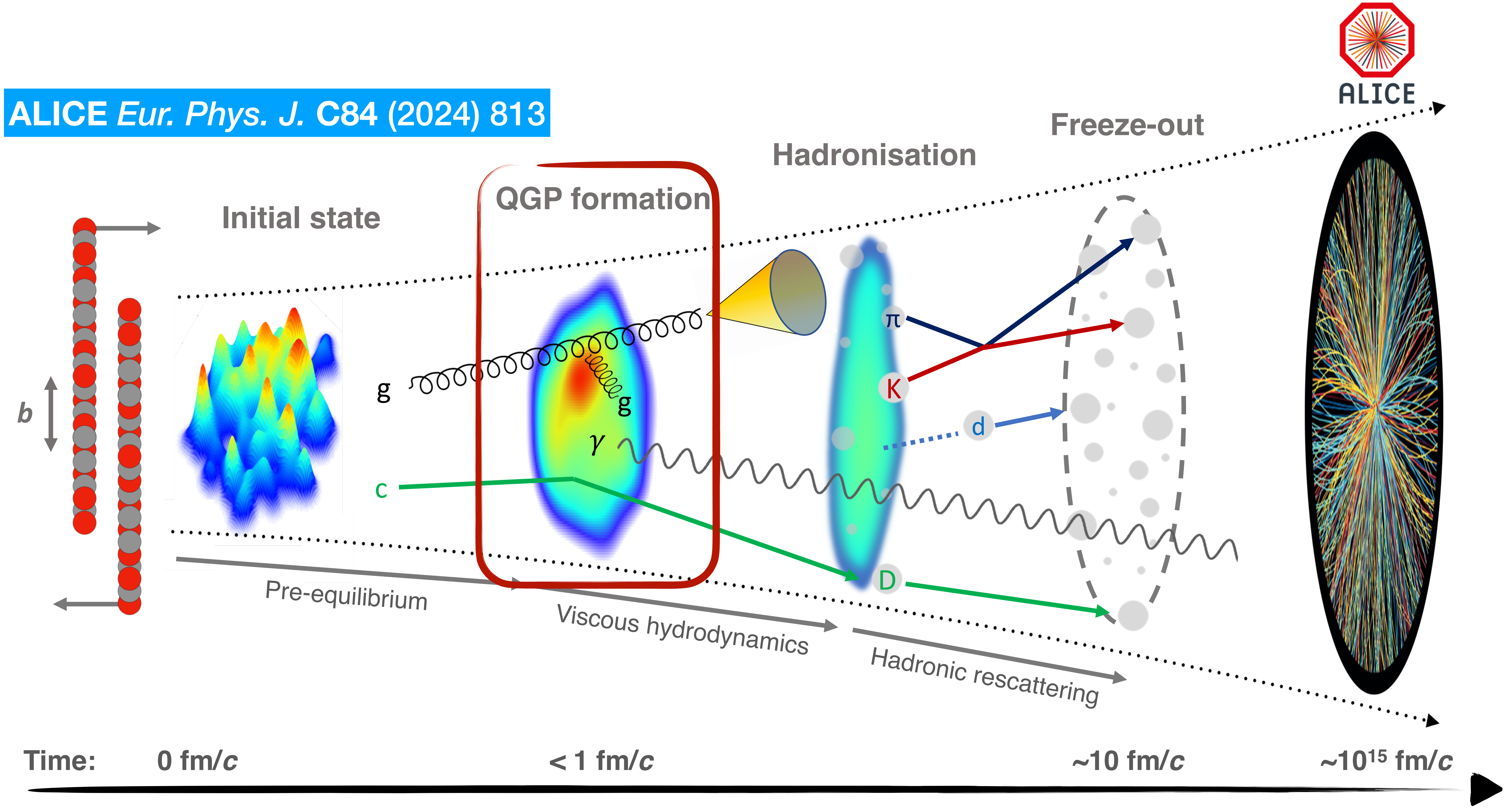
QCD at extreme conditions

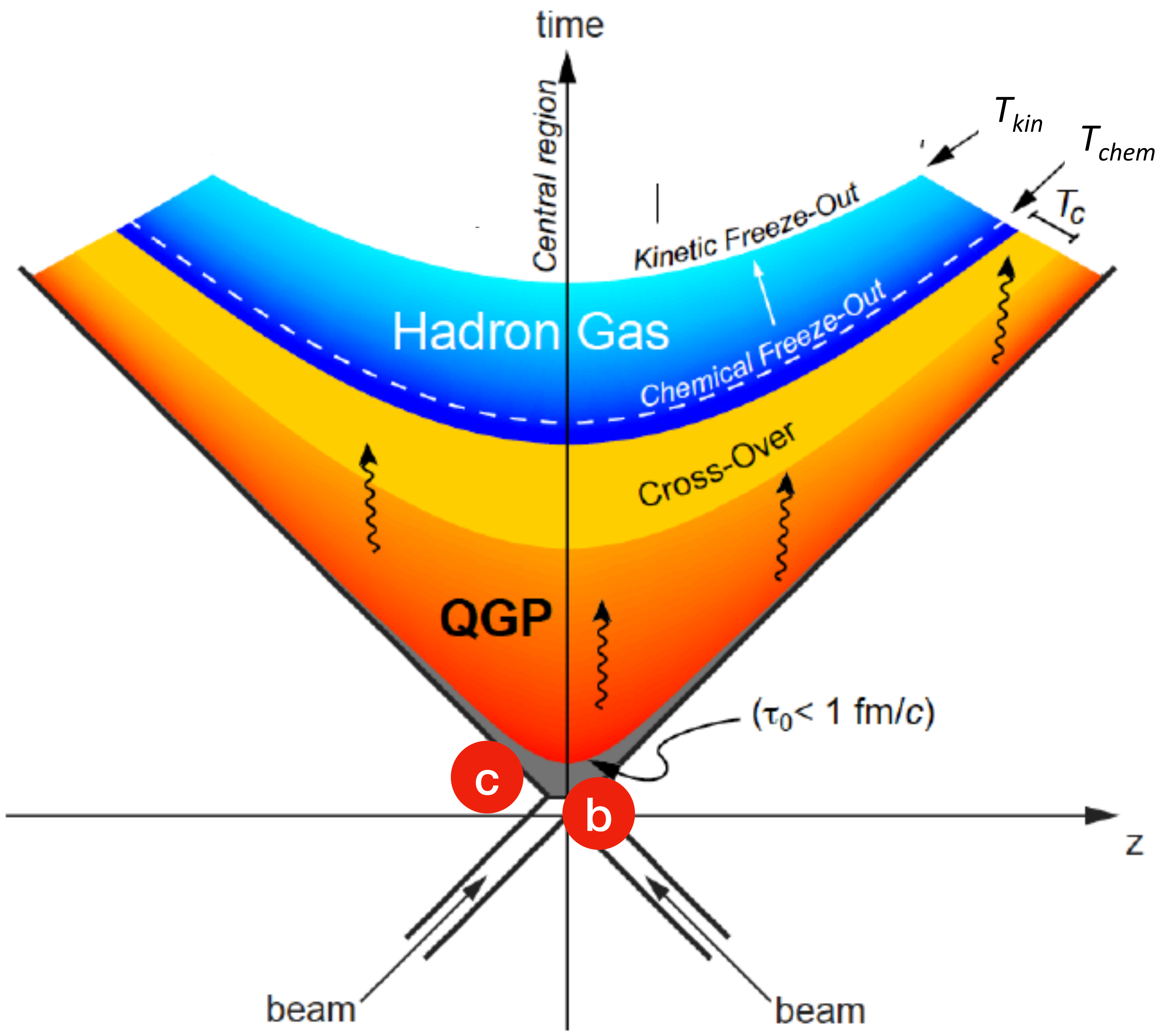
Ultra-relativistic heavy-ion collisions — formation of **quark-gluon plasma (QGP)**

ALICE *Eur. Phys. J.* **C84** (2024) 813



Heavy quark transport

Heavy quarks (charm and beauty): produced at the early stage of heavy-ion collisions before the QGP creation



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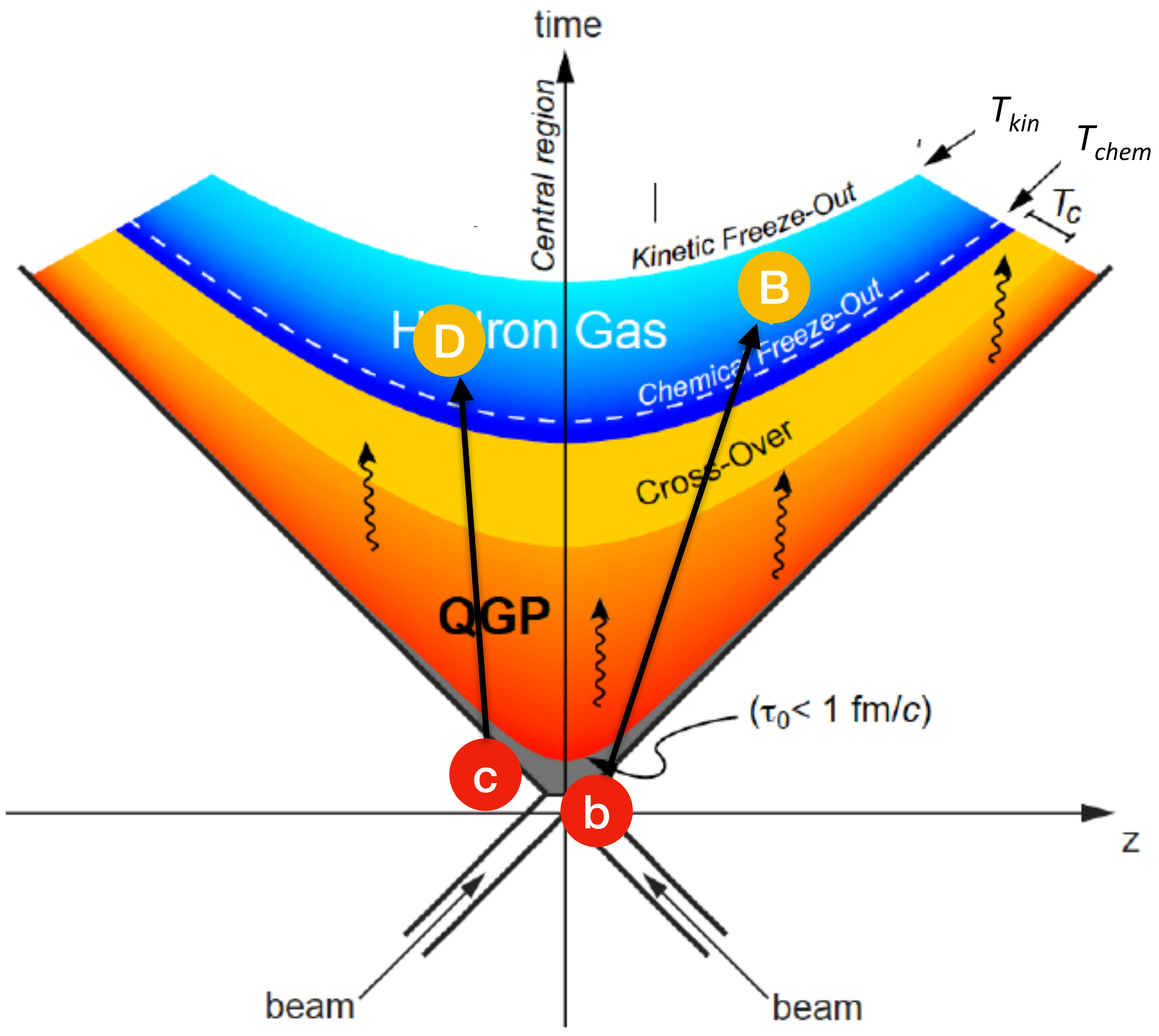

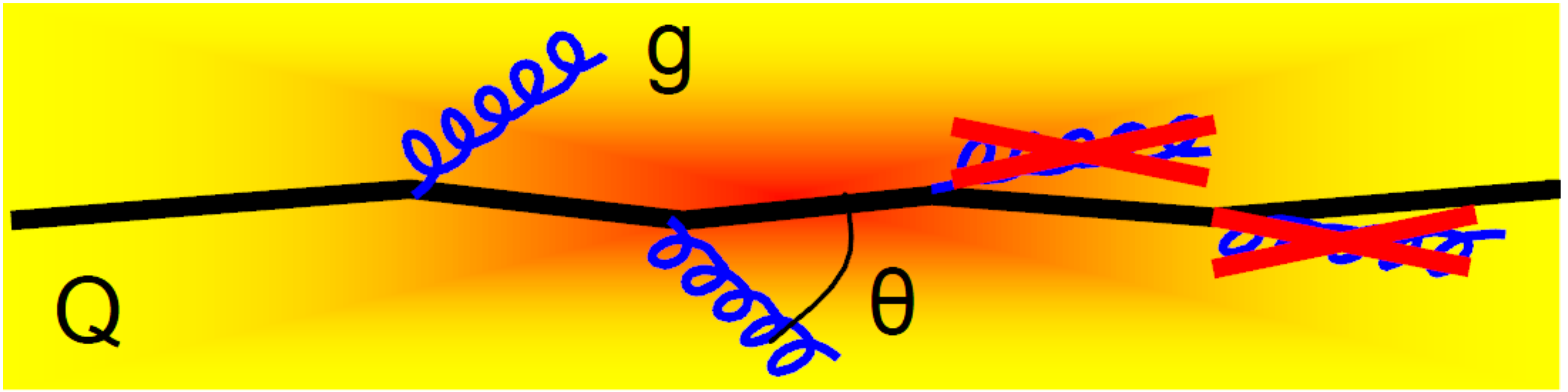

Energy loss in QGP medium

$$R_{\rm AA}(p_{\rm T}) = \frac{{\rm d}N_{\rm AA}/{\rm d}p_{\rm T}}{< T_{\rm AA} > {\rm d}\sigma_{\rm pp}/{\rm d}p_{\rm T}}$$

QCD medium

QCD vacuum

- $R_{\rm AA}$ = 1 if no medium effect and/or initial state effects
- Radiative vs. collisional energy loss

Heavy quark transport

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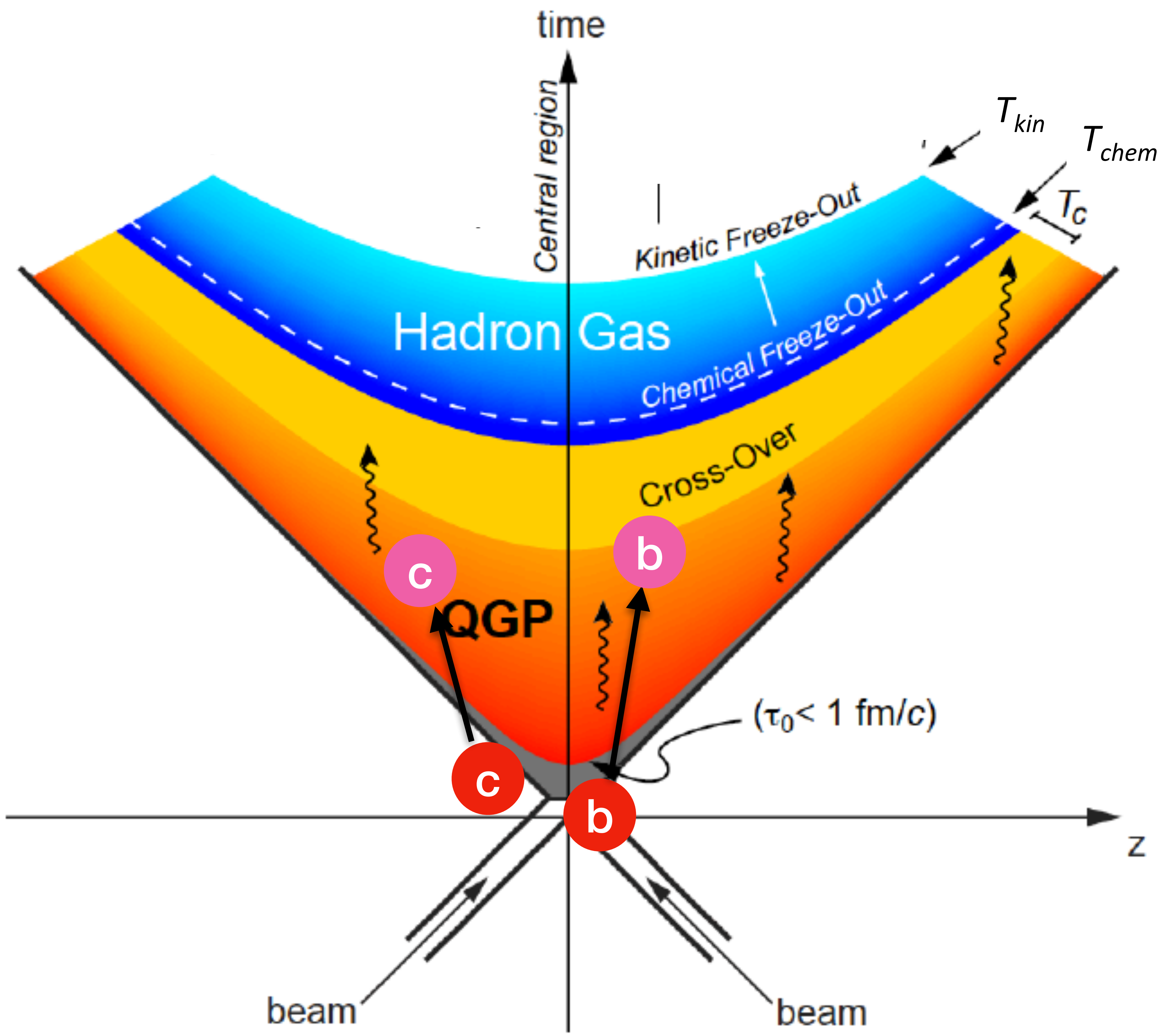
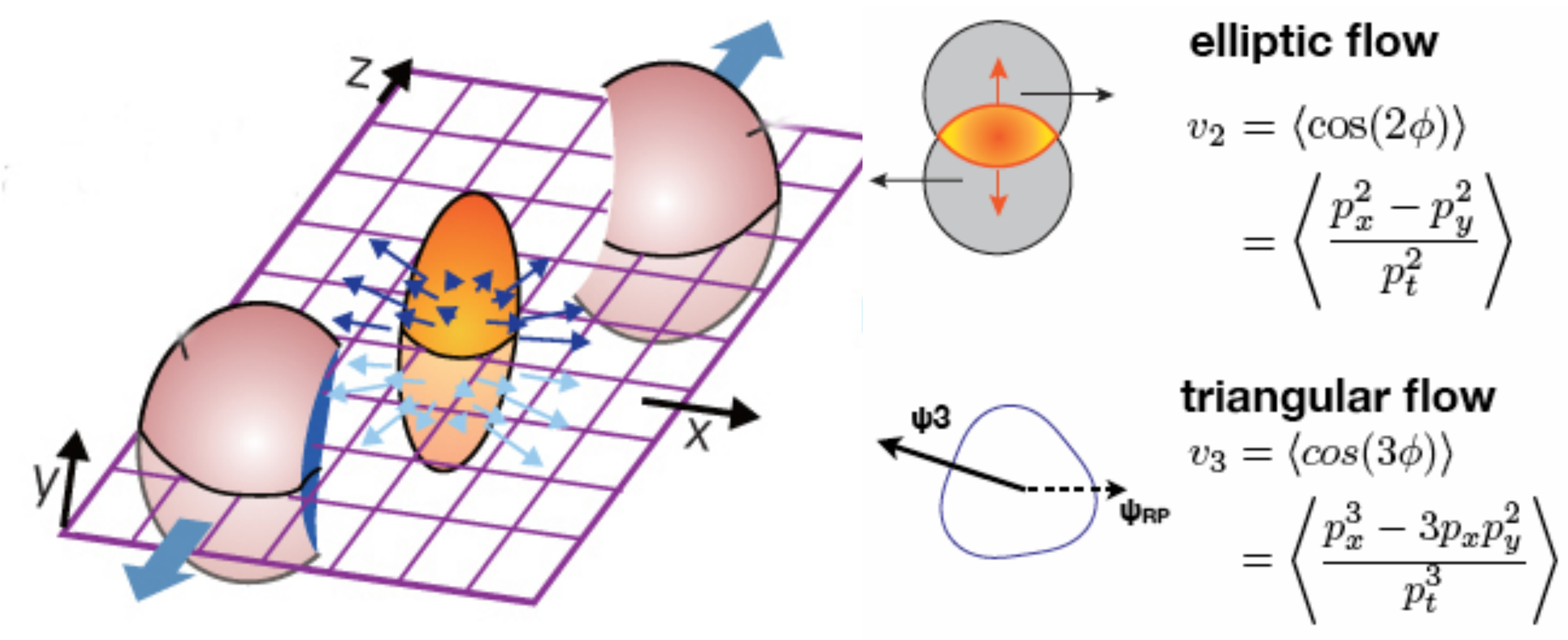


Collective expansion

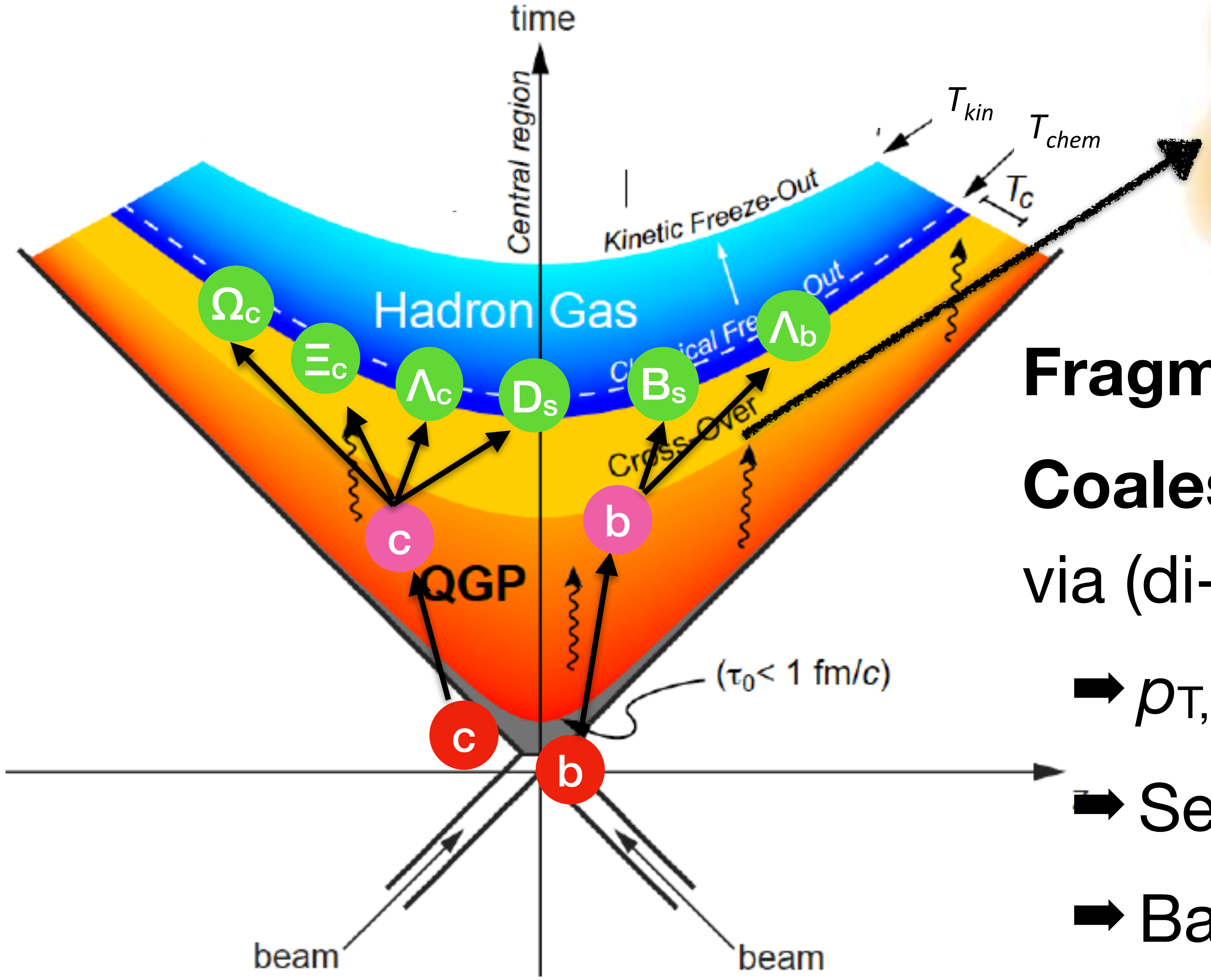
➡ Anisotropic flow

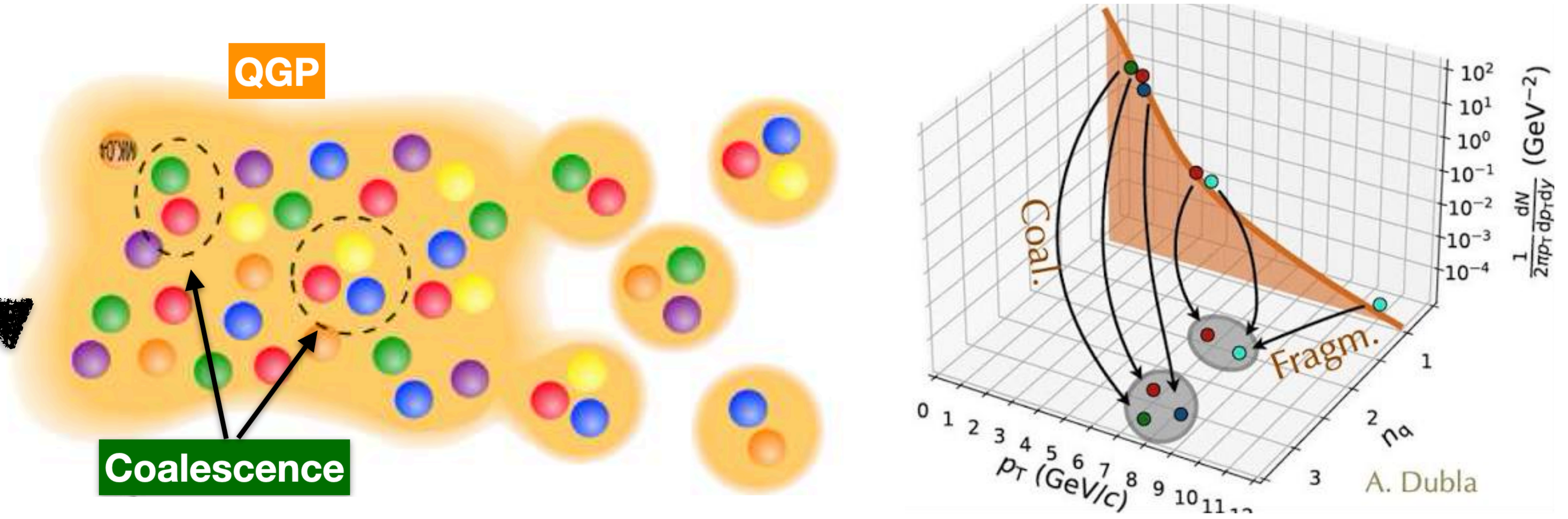


➡ Results in complex azimuthal structure of final-state particles

Heavy quark transport

Heavy quarks (charm and beauty): produced at the early stage of the collisions before the QGP creation





Fragmentation — hadrons from high p_T partons

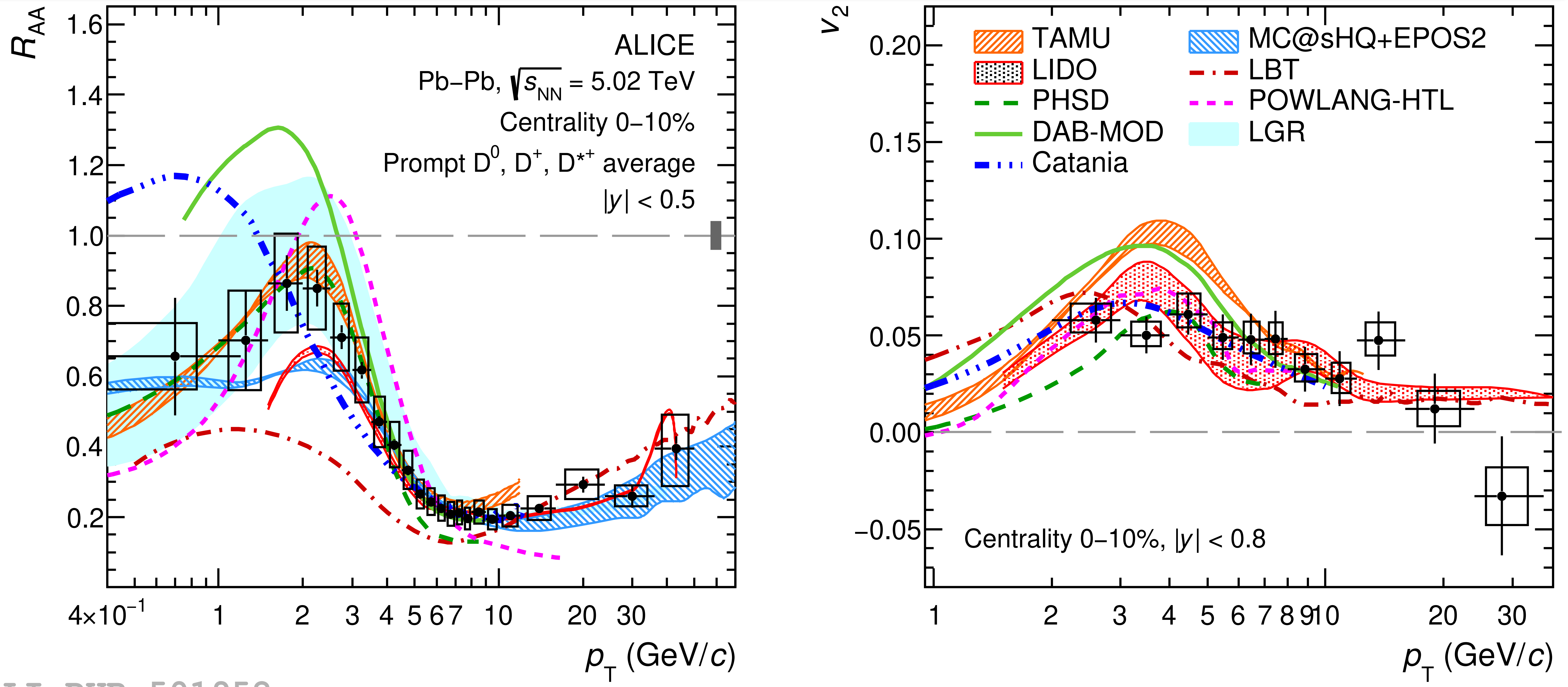
Coalescence/recombination — hadron formation via (di-)quark combination in the QGP medium

➡ $p_{T,\mathrm{hadron}} \simeq n\, p_{T,\mathrm{parton}}$, n = 2 (meson), 3 (baryon)

➡ Sensitive to baryon and meson species

➡ Baryons from lower momenta partons (denser)

R_{AA} and v_2 of D mesons



ALI-PUB-501952

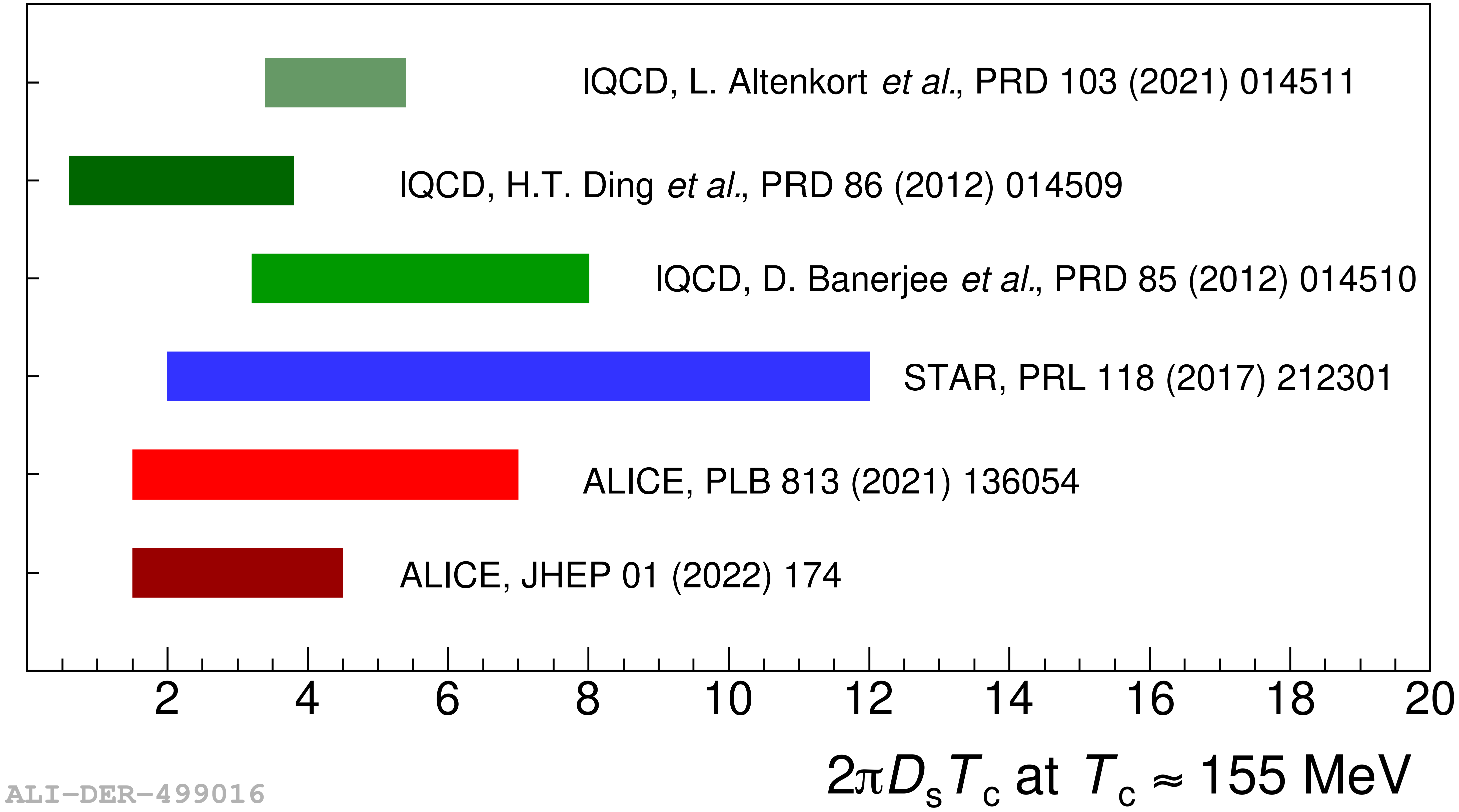
ALICE *JHEP* **2201** (2022) 174
ALICE *Phys. Lett.* **B813** (2021) 136054

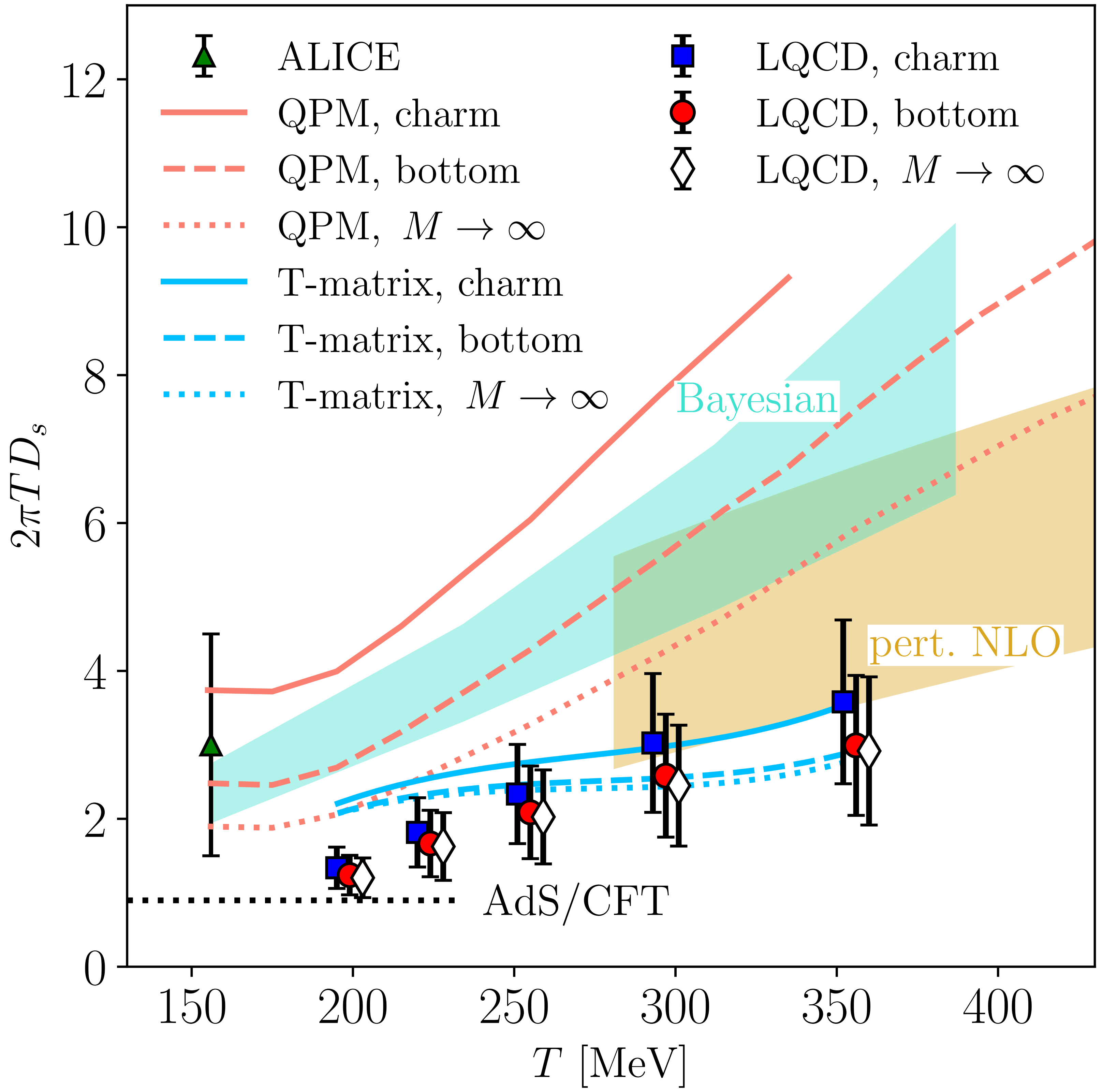
CMS *Phys. Lett.* **B816** (2021) 136253
CMS *Phys. Lett.* **B782** (2018) 474

TAMU *Phys. Rev. Lett.* **124** (2020) 042301
LIDO *Phys. Rev.* **C100** (2019) 064911
PHSD *Phys. Rev.* **C92** (2015) 014910
DAB-MOD *Phys. Rev.* **C102** (2020) 024906
MC@sHQ+EPOS2 *Phys. Rev.* **C89** (2014) 014905

Catania *Phys. Lett.* **B805** (2020) 135460
LBT *Phys. Lett.* **B777** (2018) 255
POWLANG-HTL *JHEP* **1802** (2018) 043
LGR *Eur. Phys. J.* **C80** (2020) 671

Charm quark transport



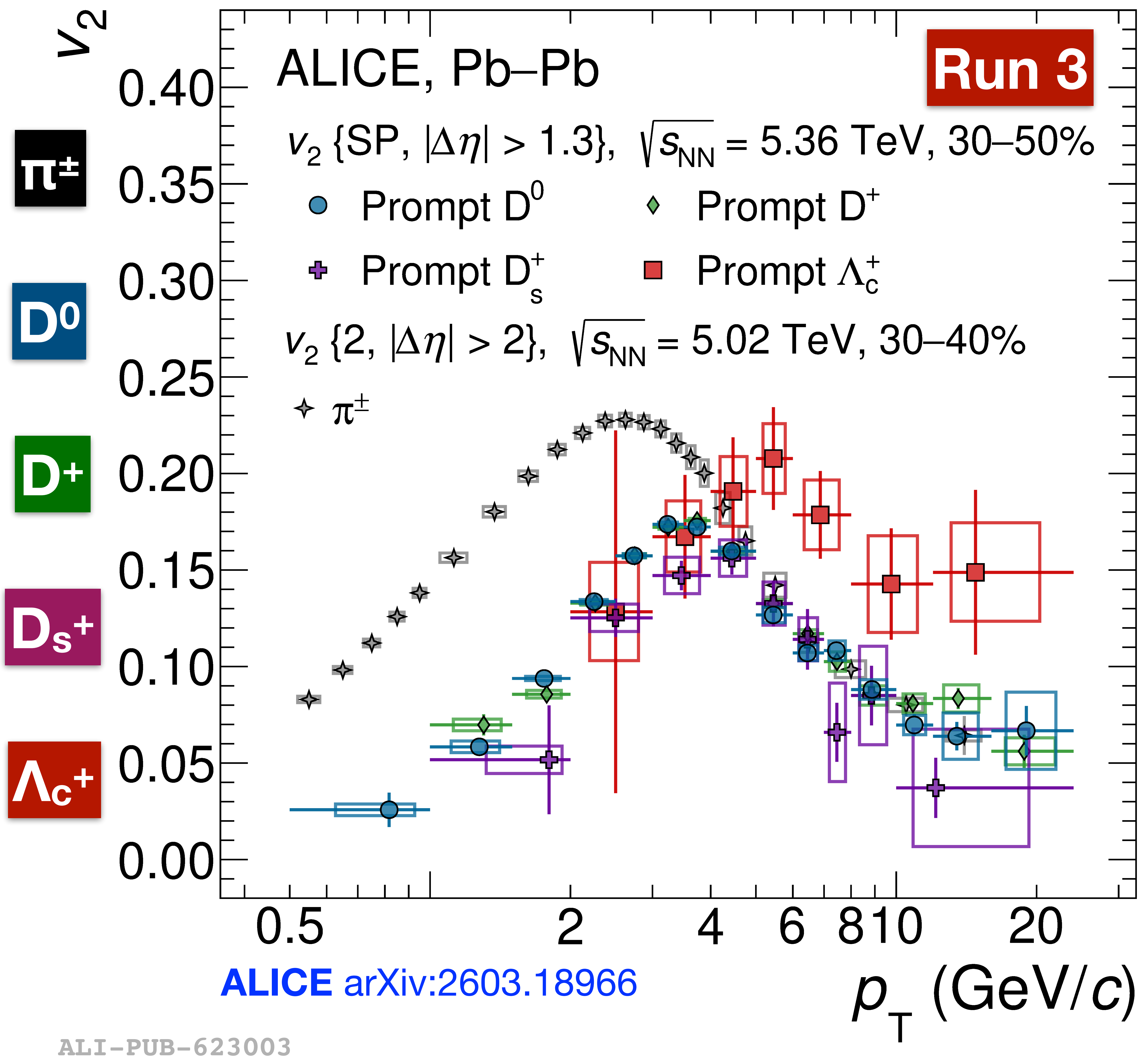


Hot QCD *Phys. Rev. Lett.* 132 (2024) 051902

$1.5 < 2\pi D_s(T) < 4.5$, $\tau_{charm} = (m_{charm} / T)\, D_s(T) = 3–9$ fm/c $< \tau_{medium} \approx 10$ fm/c

➡ Indicate charm may thermalize in the QCD medium

Charmed hadron flow



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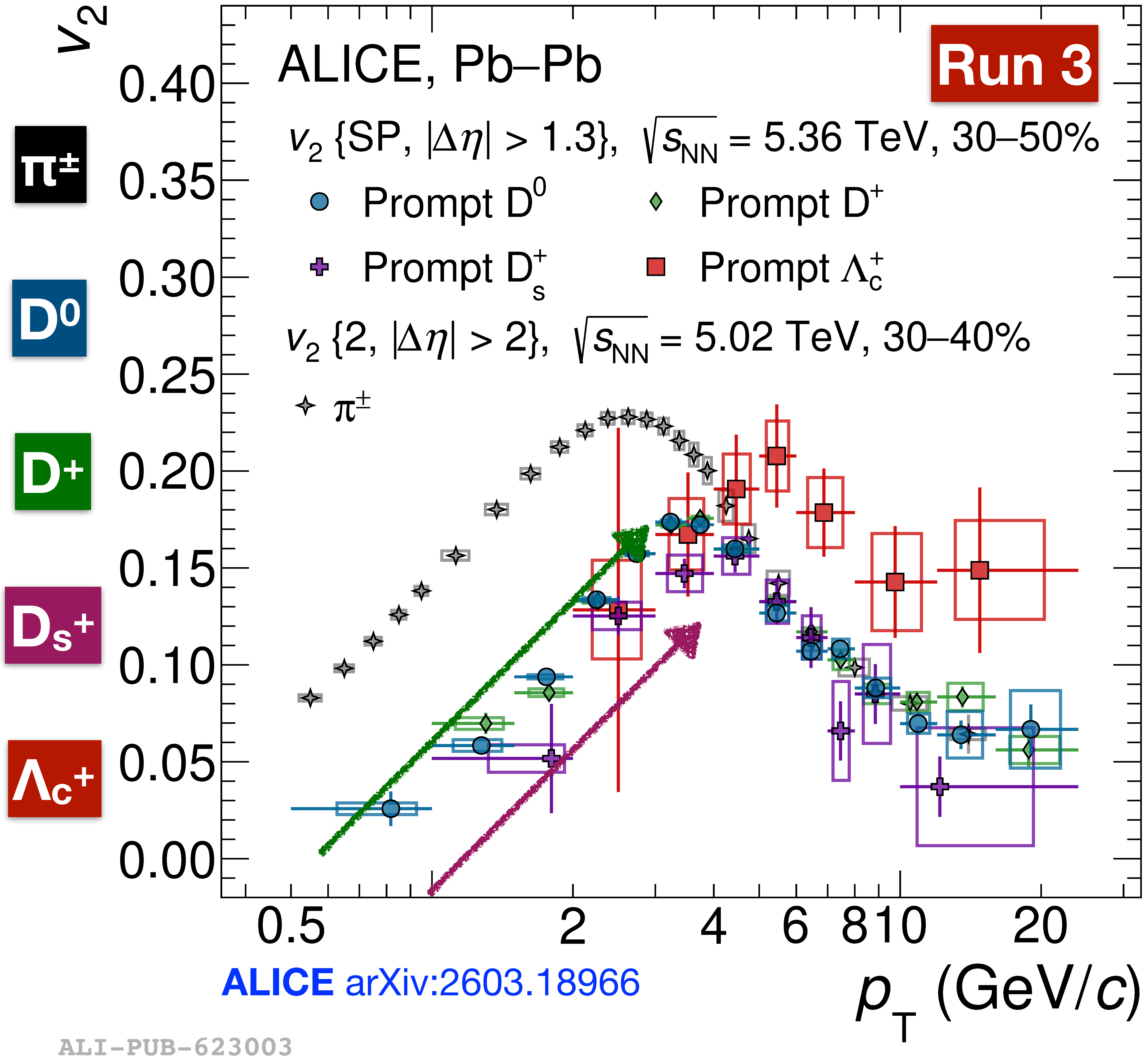


Low and intermediate–p_T

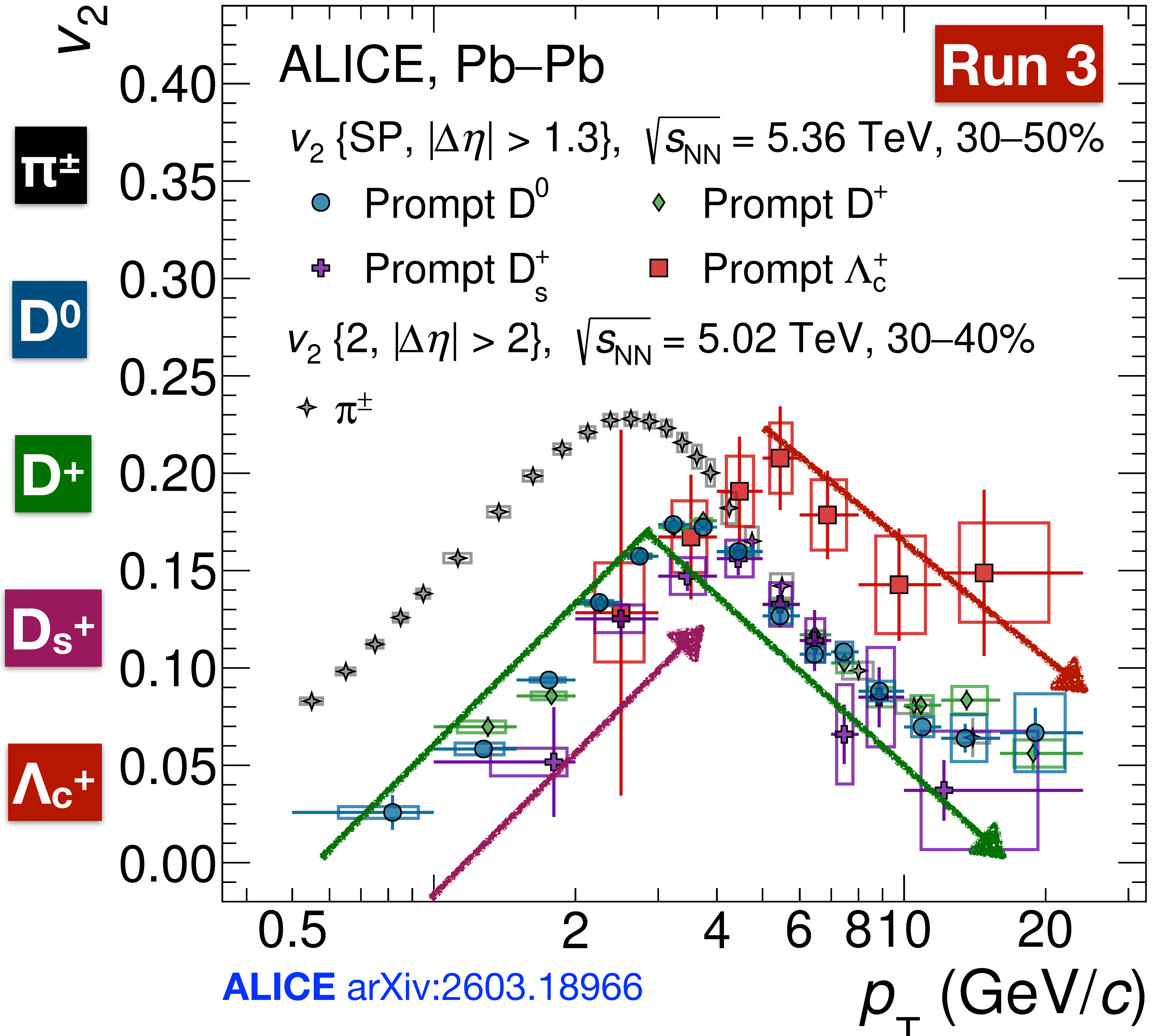
$\boxed{v_2(D_s^\pm) < v_2(D^0) \approx v_2(D^\pm)} < v_2(\pi^\pm)$

➡ Sequential hadronization

Zhuang *et al.*, *Phys. Rev. Lett.* **136** (2026) 232301

Springer Proc. Phys. **250** (2020) 275

Charmed hadron flow



ALICE arXiv:2603.18966

ALI-PUB-623003

Low and intermediate–p_T

$v_2(D_s^{\pm}) < v_2(D^0) \approx v_2(D^{\pm}) < v_2(\pi^{\pm})$

➡ Sequential hadronization

Zhuang *et al.*, *Phys. Rev. Lett.* **136** (2026) 232301

Springer Proc. Phys. **250** (2020) 275

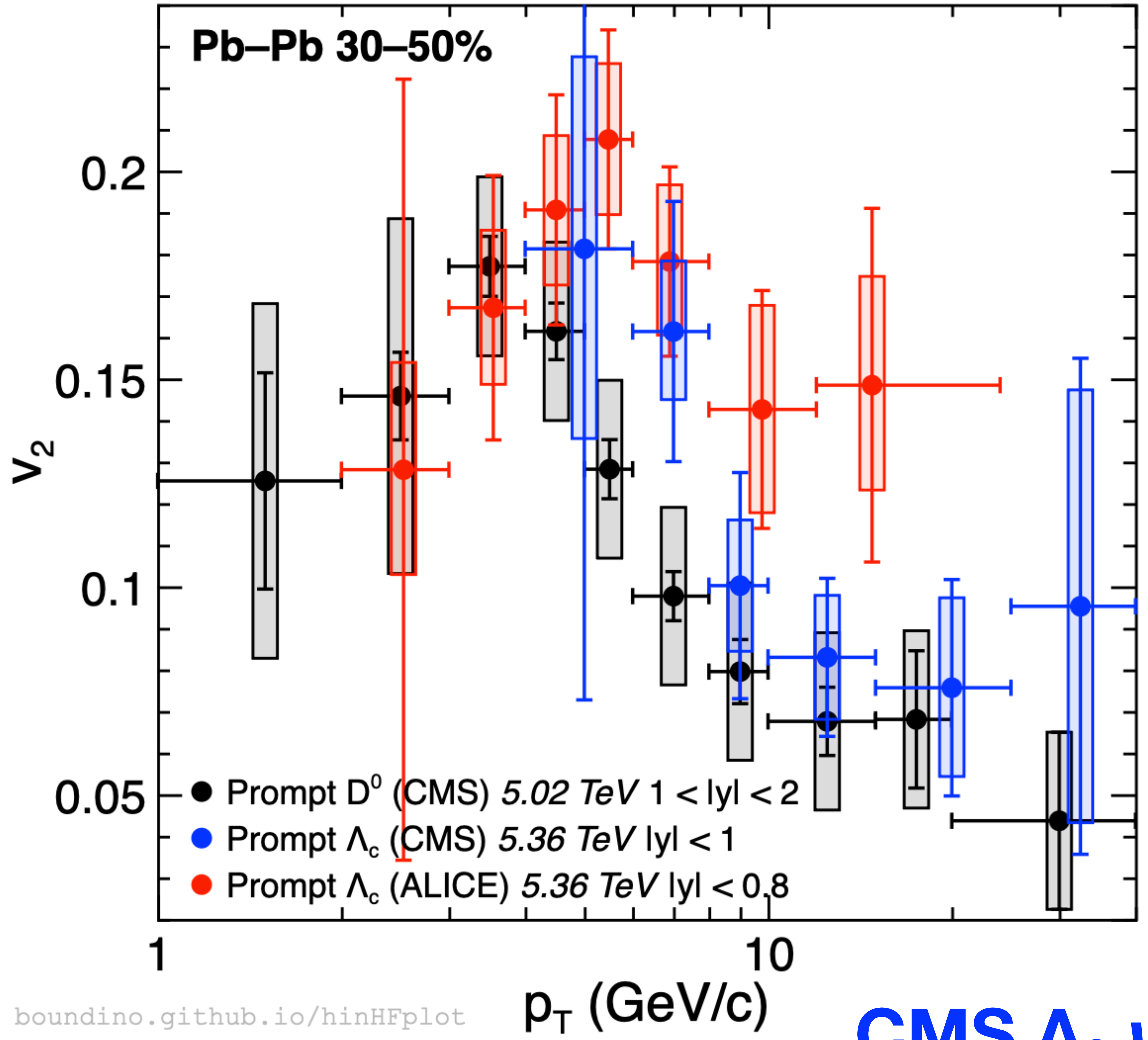
Intermediate and high-p_T

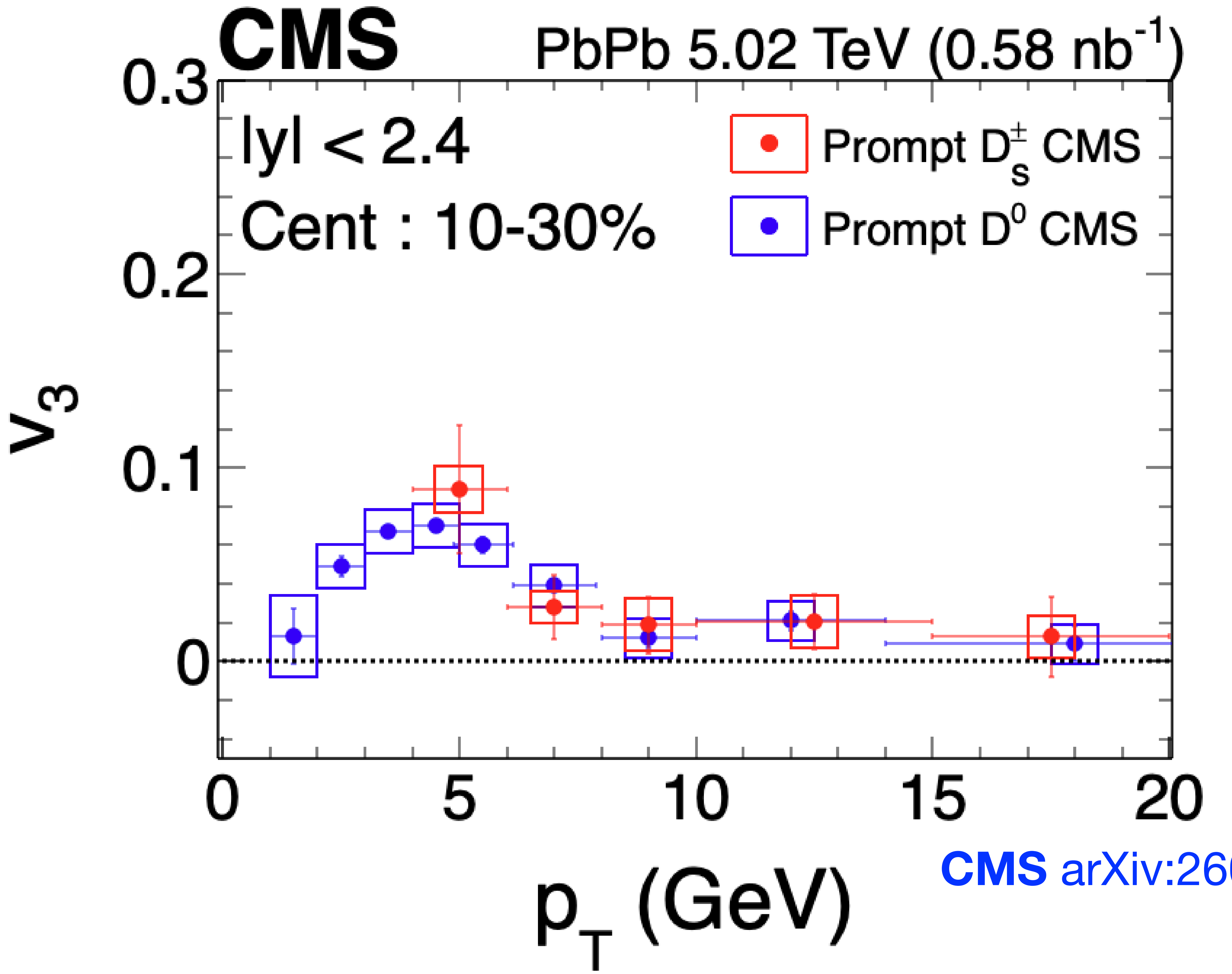
$v_2(\Lambda_c^+) > v_2(D_s^+) \approx v_2(D^0) \approx v_2(D^+) \approx v_2(\pi^{\pm})$

➡ Strong evidence of coalescence

Further reveal the transport dynamics of heavy quarks in the QGP medium and provide high-precision microscope tomography of the QGP

Charmed hadron flow





CMS arXiv:2602.14221

ALICE arXiv:2603.18966

CMS PAS-HIN-25-022

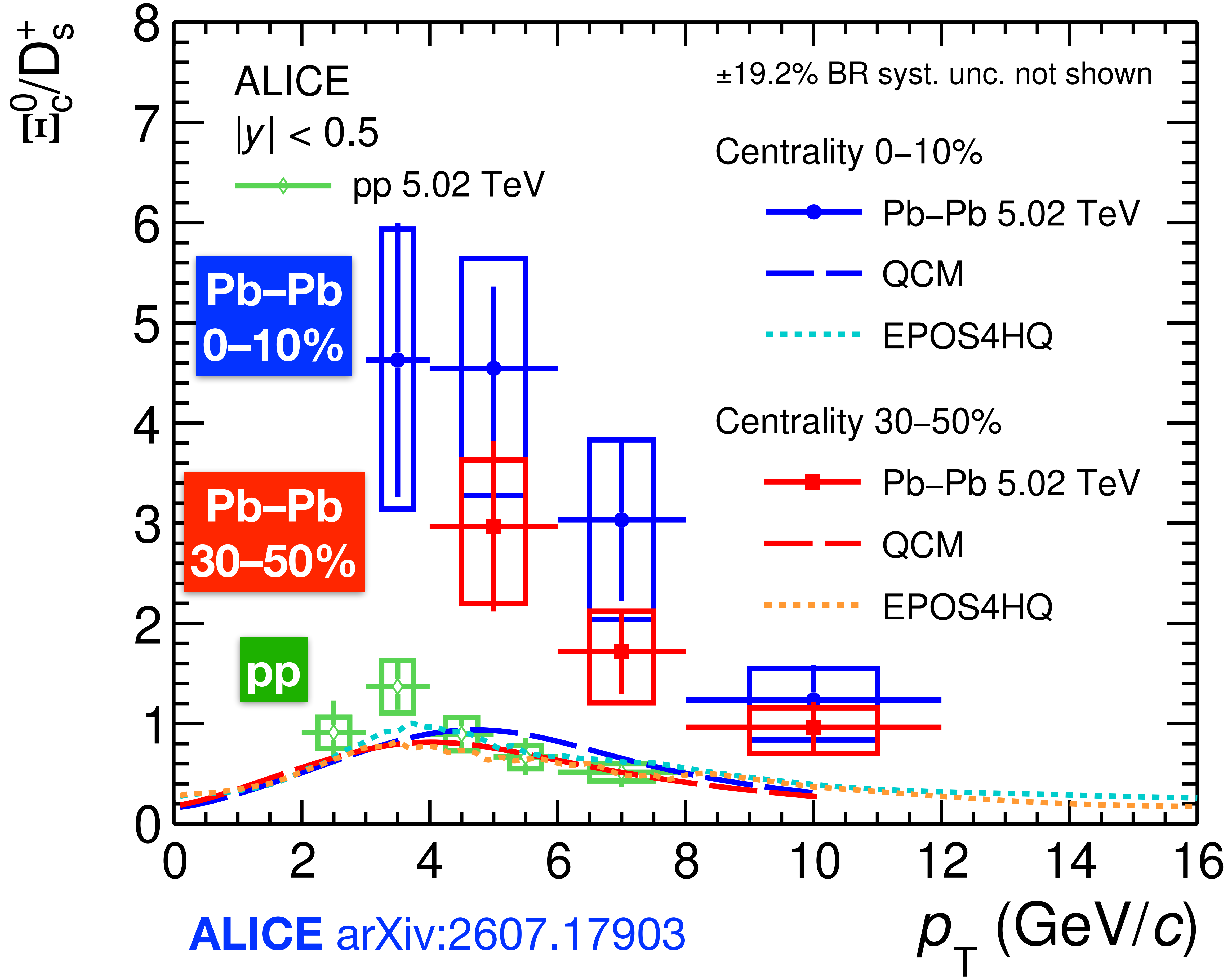
CMS *Phys. Lett.* **B816** (2021) 136253

CMS Λ_c v_2 Consistent with ALICE in the overlapped p_T

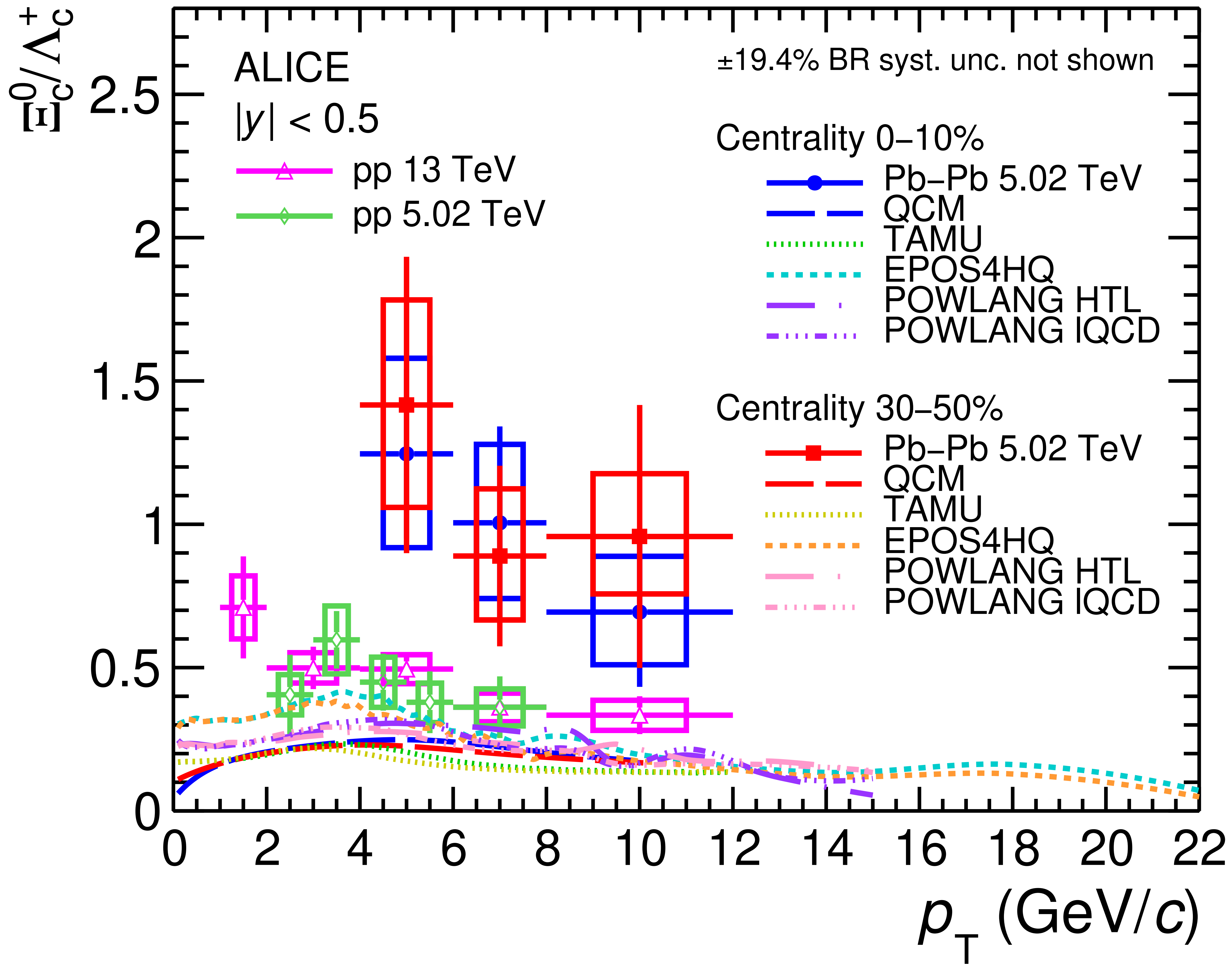
➡ Further constraint on energy loss at higher p_T

D meson v_3 Insensitive to strangeness content

Ξ_c production in Pb–Pb



ALI-PUB-639062

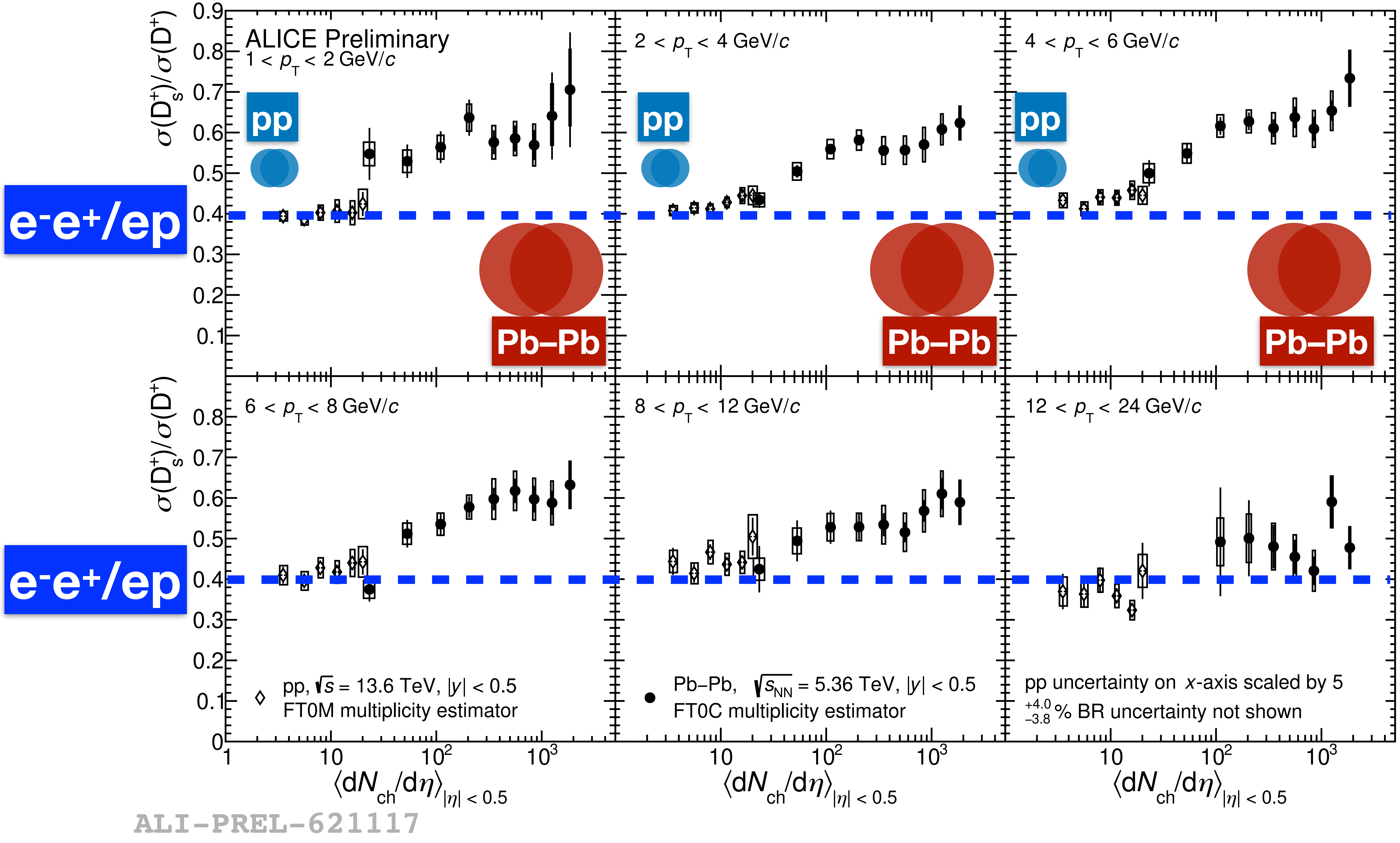


ALI-PUB-639067

Both Ξ_c^0/D_s^+ and Ξ_c^0/Λ_c^+ ratios are enhanced Pb–Pb compared to pp

➡ Challenging the model predictions

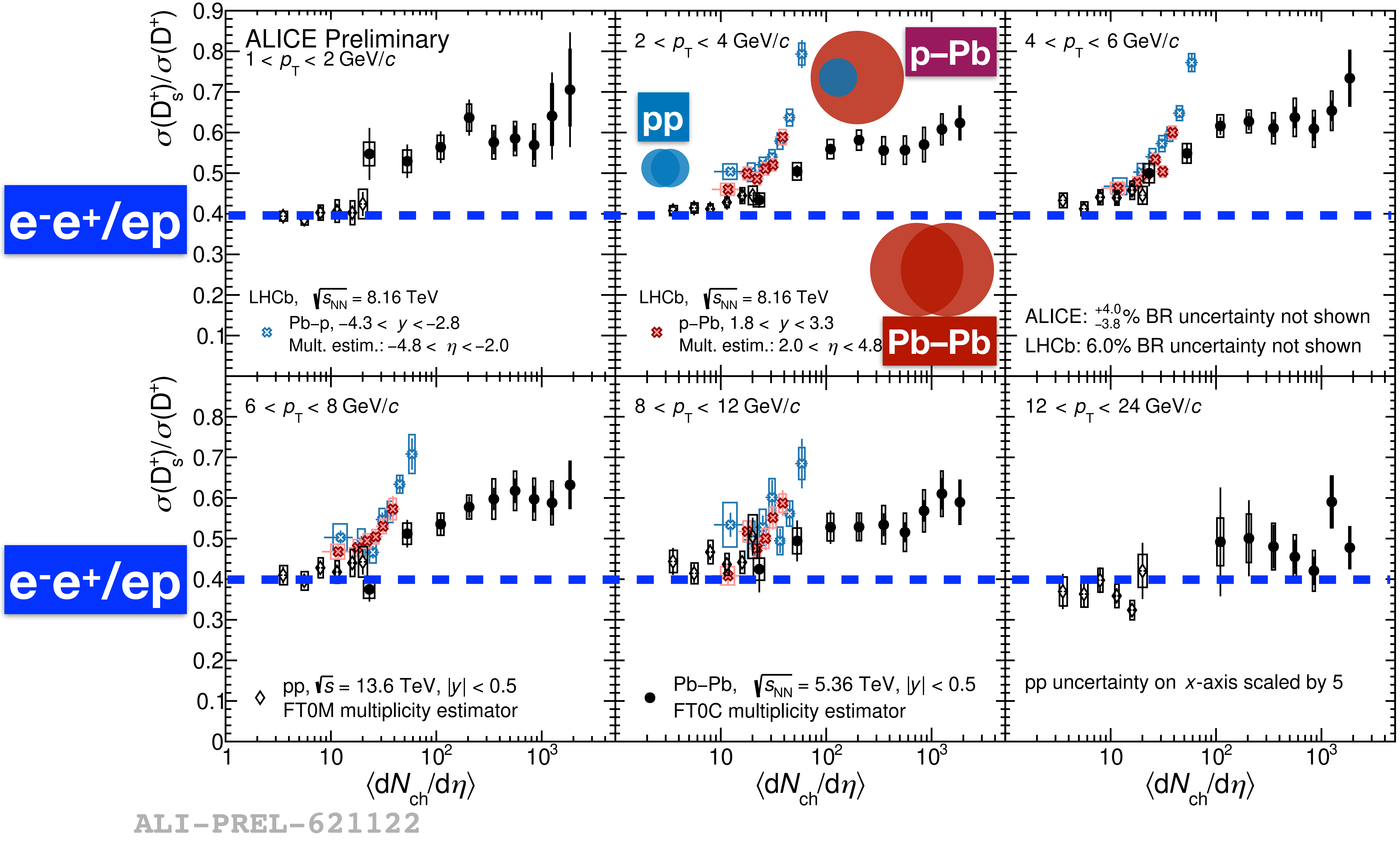
D_s^+/D^+ ratio vs. multiplicity



pp Consistent with LEP and independent on p_T and multiplicity

Pb–Pb Increase with multiplicity at intermediate-p_T

D_s^+/D^+ ratio vs. multiplicity



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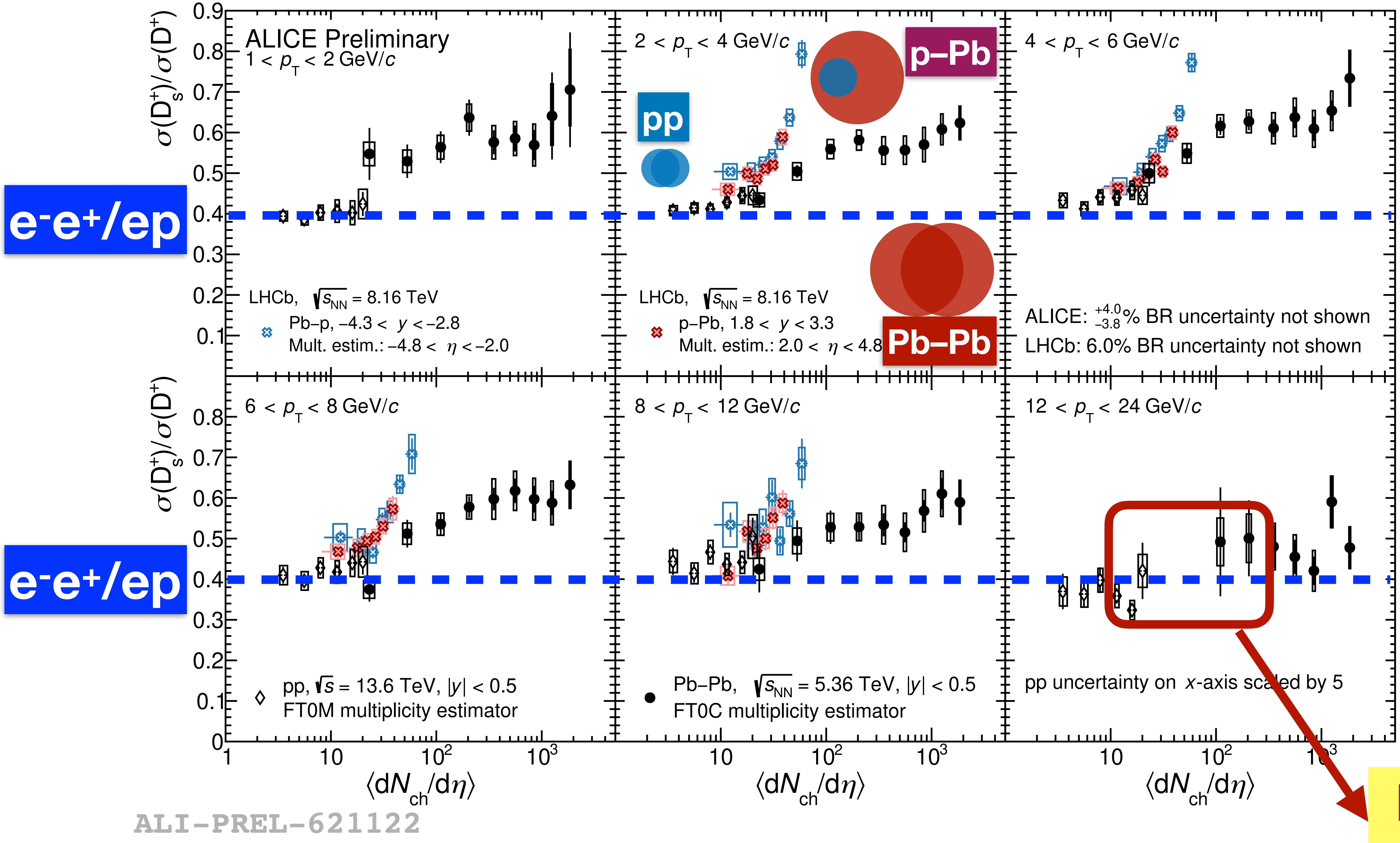
Pb–Pb Increase with multiplicity at intermediate-p_T

p–Pb Steeper increasing

➡ LHCb measurements in different rapidity

D_s^+/D^+ ratio vs. multiplicity



pp Consistent with LEP and independent on p_T and multiplicity

Pb–Pb Increase with multiplicity at intermediate-p_T

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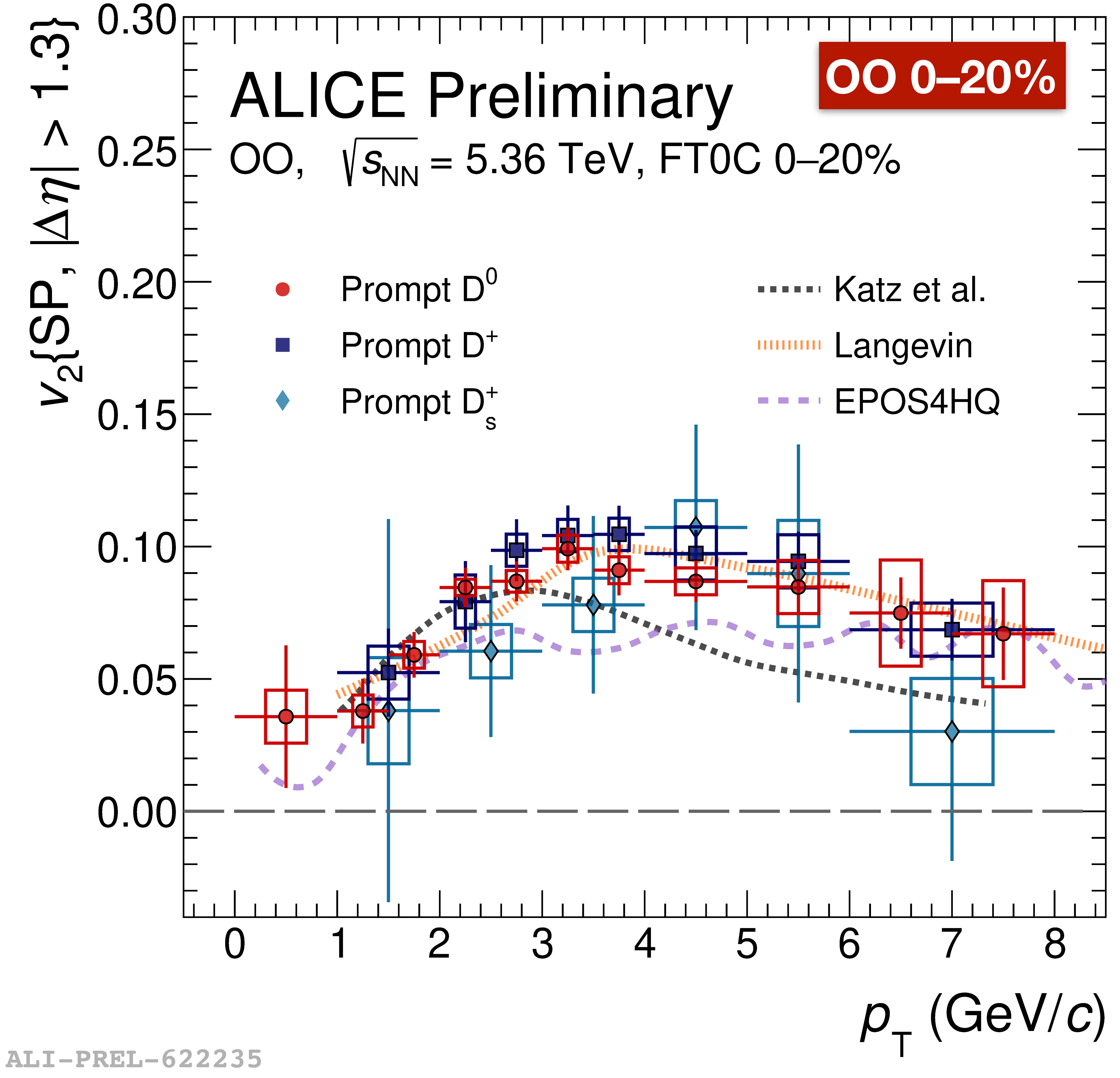
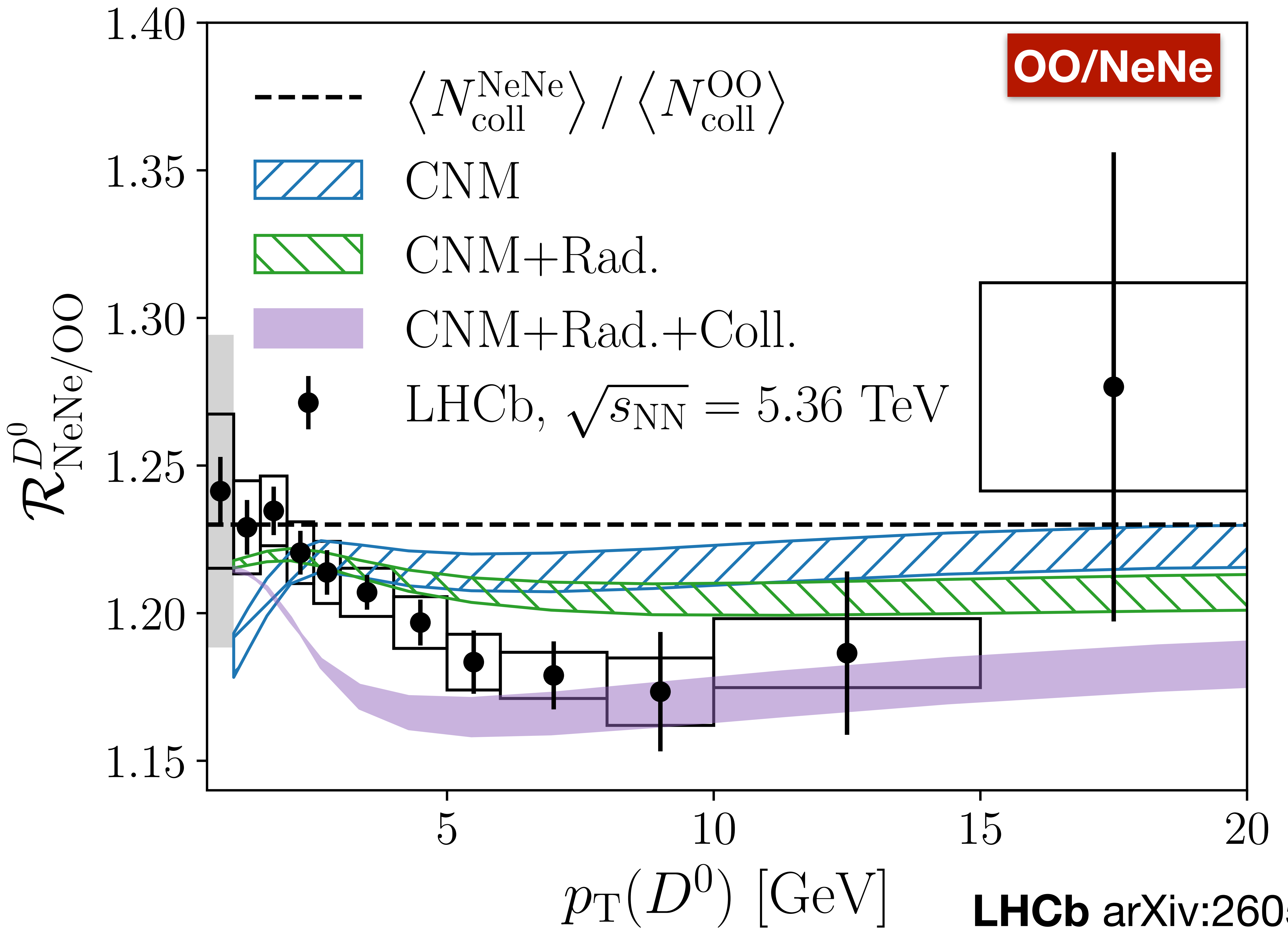
➡ LHCb measurements in different rapidity

Light-ion systems are important to fill the gap

D meson production in light-ions

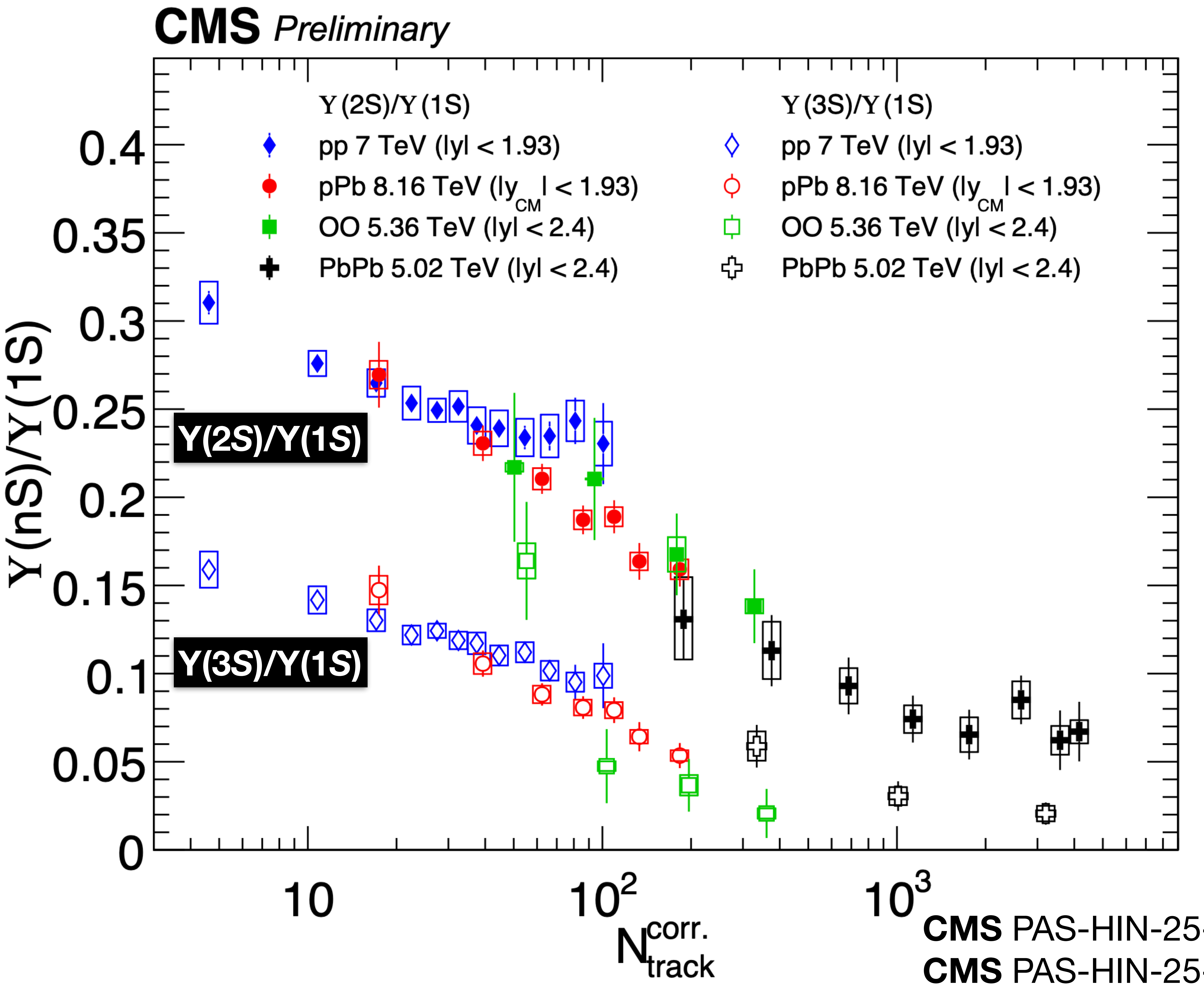




LHCb arXiv:2605.27273

- D meson v_2 in OO agrees with models including QGP formation
- D^0 yield ratio between OO and Ne–Ne —Consistent with QGP effects

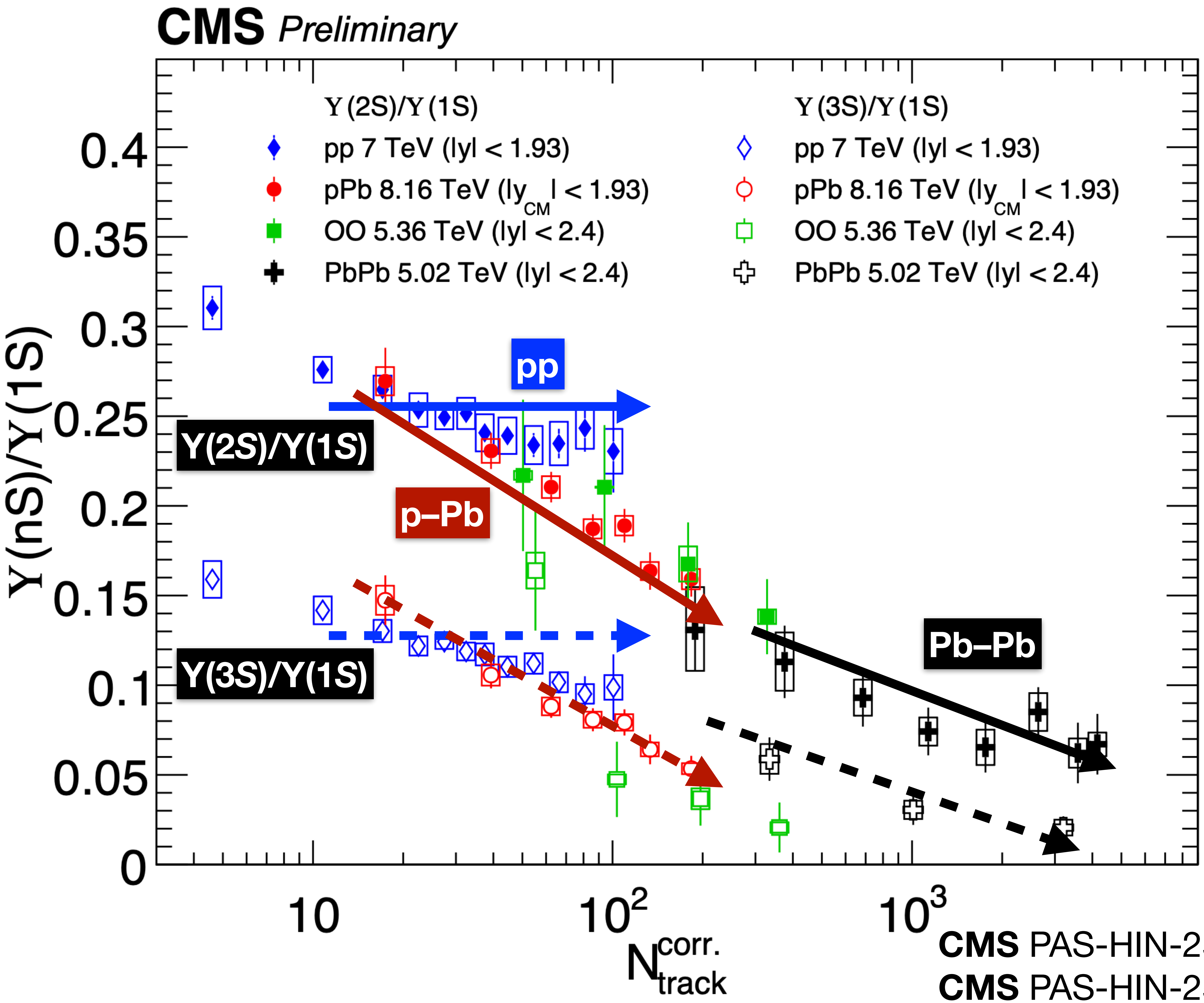
Υ production across systems



CMS PAS-HIN-25-015
CMS PAS-HIN-25-005

See also **LHCb** PAPER-2026-027

Υ production across systems



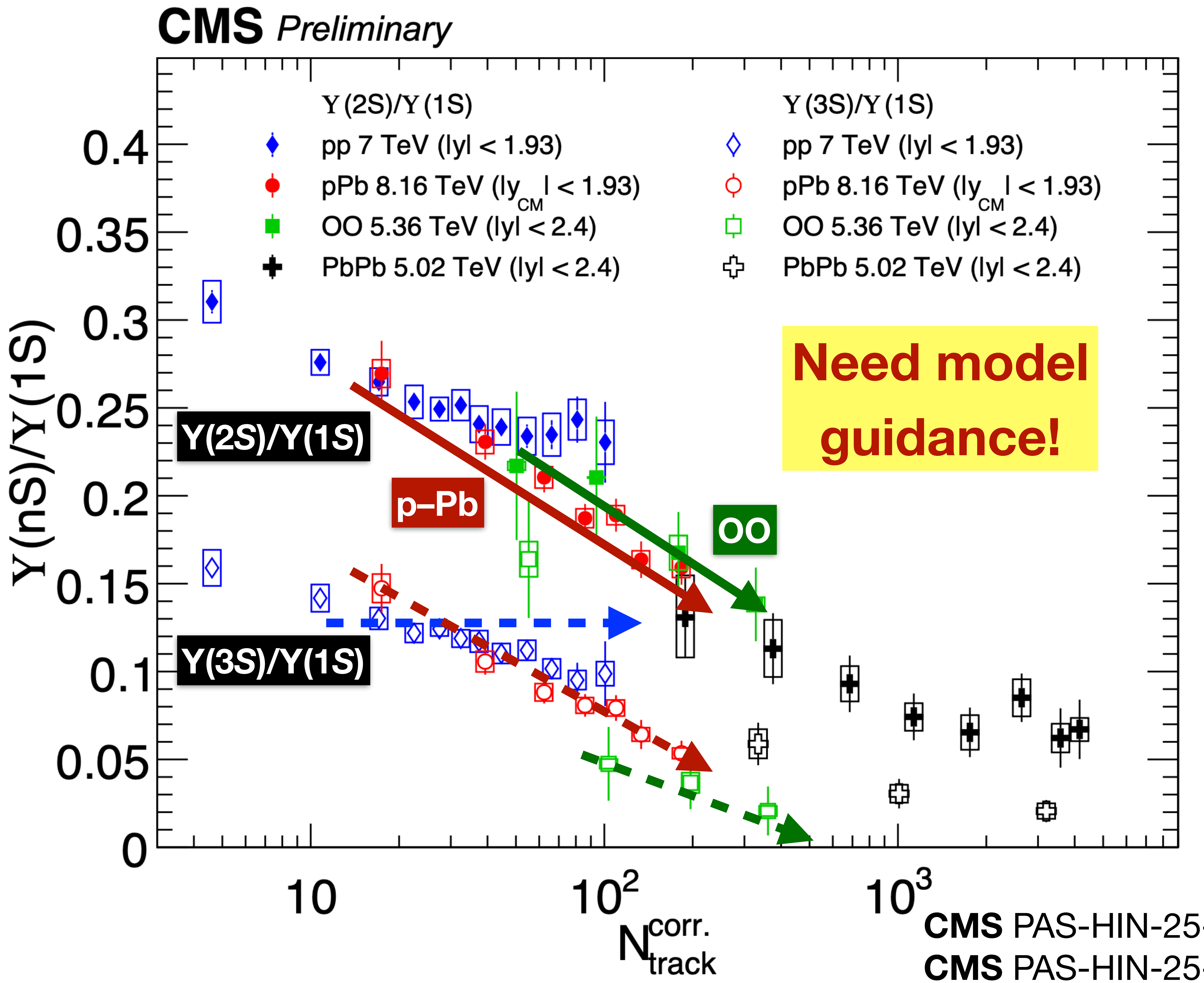
p–Pb and **pp** consistent at low multiplicity, no flattening seen in **p–Pb** at high multiplicity

Rather smooth evolution of suppression between **p–Pb** and **Pb–Pb**

CMS PAS-HIN-25-015
CMS PAS-HIN-25-005

See also **LHCb** PAPER-2026-027

Υ production across systems



p–Pb and **pp** consistent at low multiplicity, no flattening seen in **p–Pb** at high multiplicity

Rather smooth evolution of suppression between **p–Pb** and **Pb–Pb**

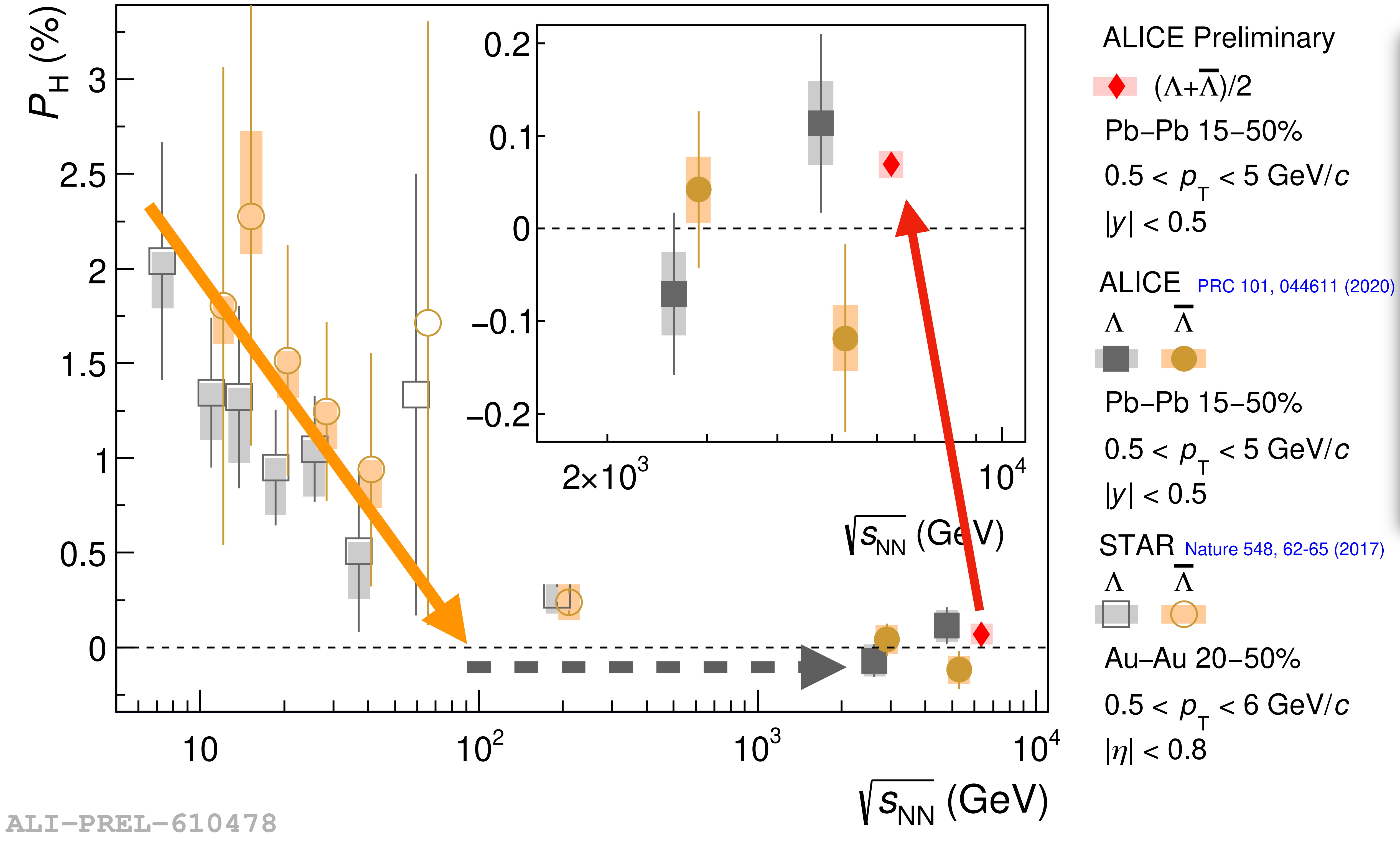
Υ(2*S*)/Υ(1*S*) trend in **OO** follows that of **p–Pb** and **Pb–Pb**

Υ(2*S*)/Υ(1*S*) in **OO** tends to be lower than **p–Pb** and **Pb–Pb**

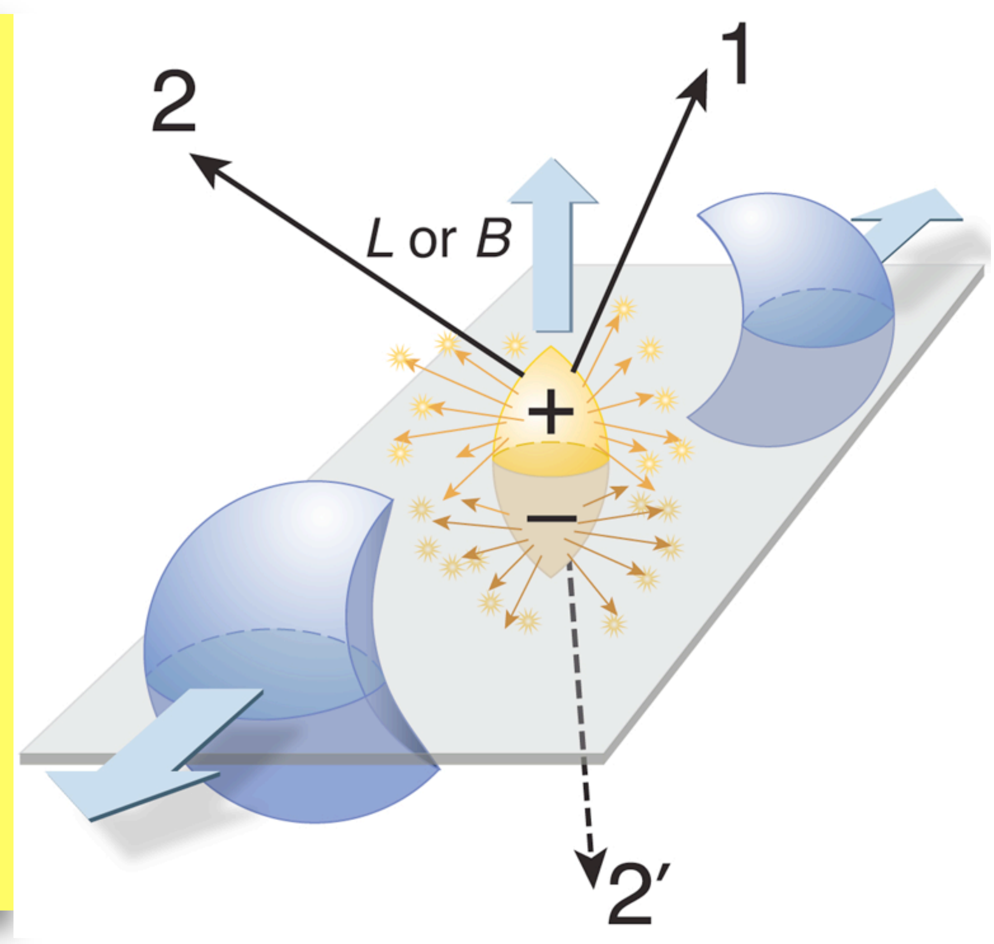
CMS PAS-HIN-25-015
CMS PAS-HIN-25-005

See also **LHCb** PAPER-2026-027

Global polarization of hyperons



Large orbital angular momentum and strong magnetic fields in non-central collisions induce global polarization



Z.-T. Liang and X.-N. Wang, *Phys. Rev. Lett.* **96** (2006) 039901
Z.-T. Liang and X.-N. Wang, *Phys. Lett.* **B629** (2005) 20
STAR *Nature* **548** (2018) 62 **STAR** *Nature* **614** (2023) 244

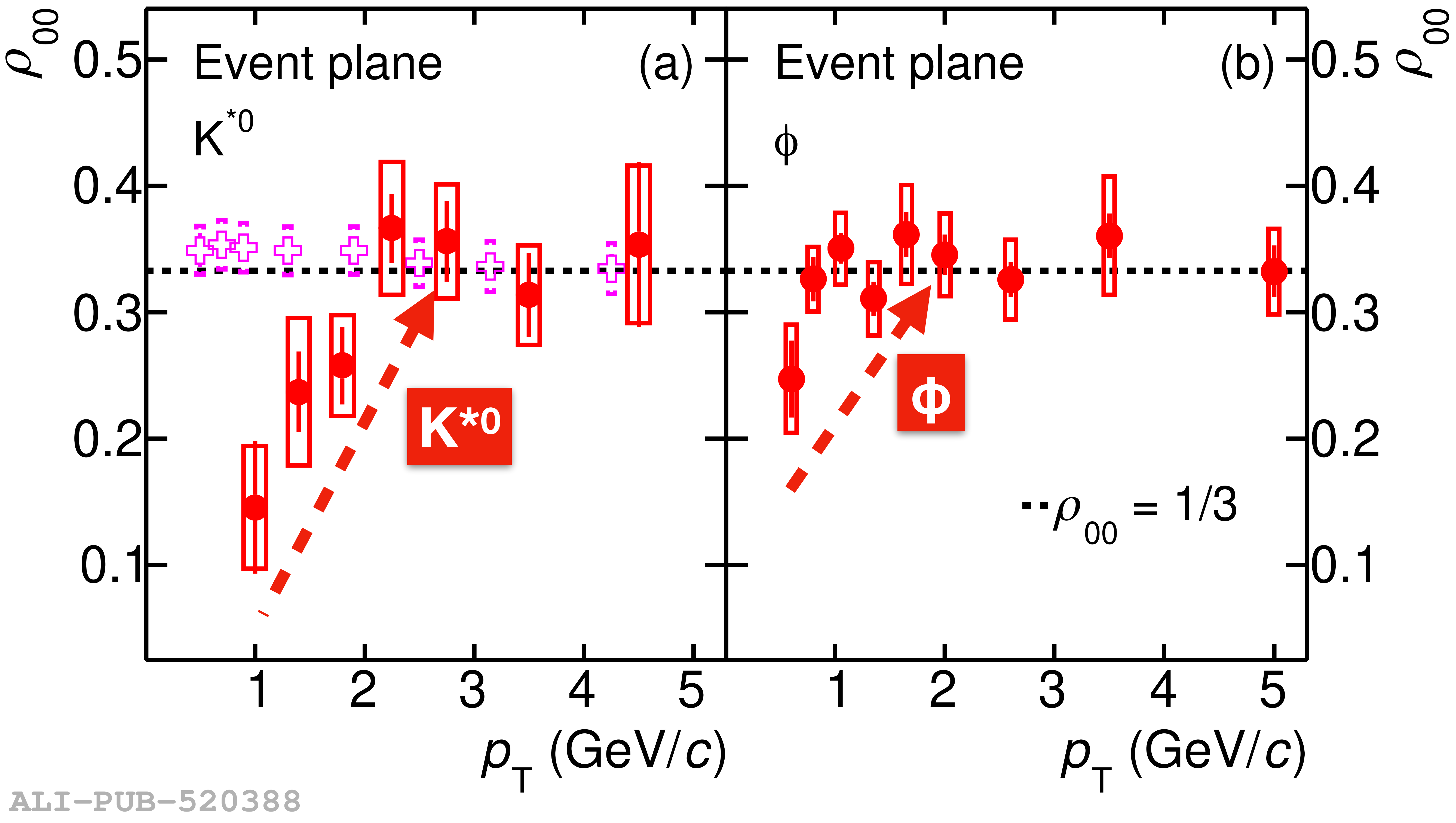
➡ LHC Run 1 and 2: Global polarization consistent with zero (large uncertainties)

➡ New Run 3: First observation of polarized hyperons at LHC energies with 5σ

Efforts ongoing for the measurement of polarization difference between particle and anti-particle, which is sensitive to magnetic field!

Spin alignment of vector mesons

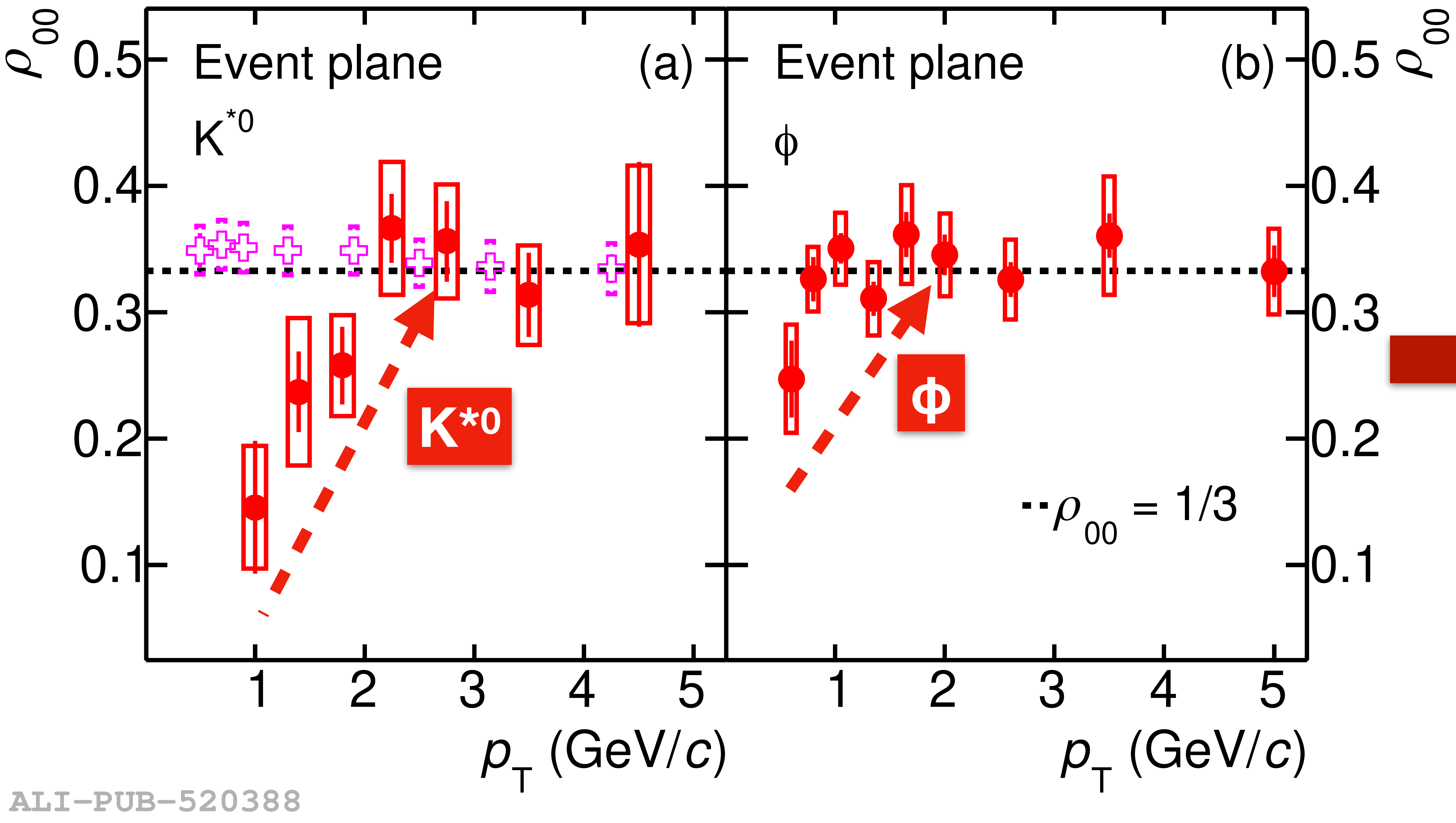
ALICE *Phys. Rev. Lett.* **125** (2020) 012301



Not consistent with early direct extrapolation from Λ measurements

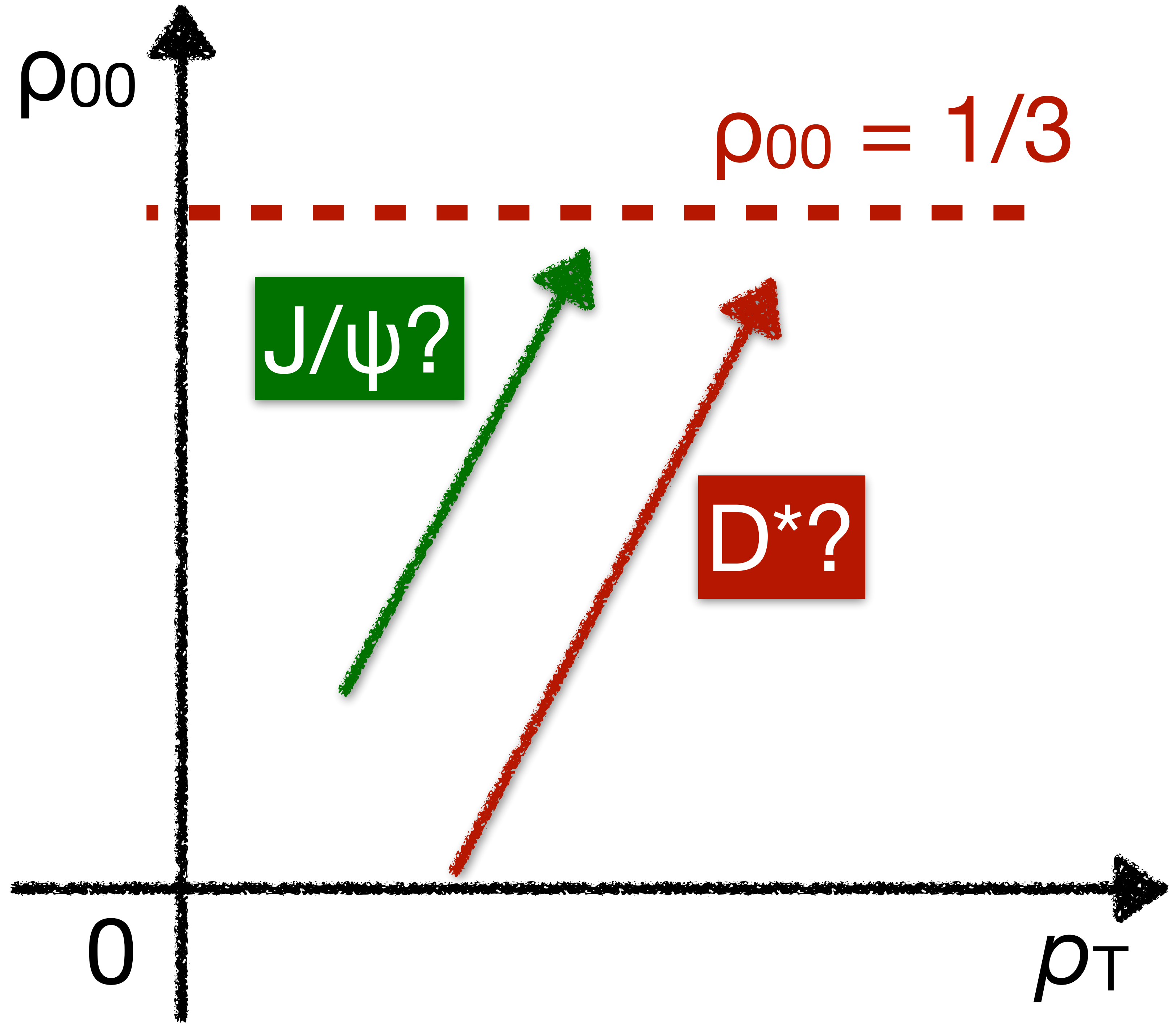
Spin alignment of vector mesons

ALICE *Phys. Rev. Lett.* **125** (2020) 012301



Not consistent with early direct extrapolation from Λ measurements

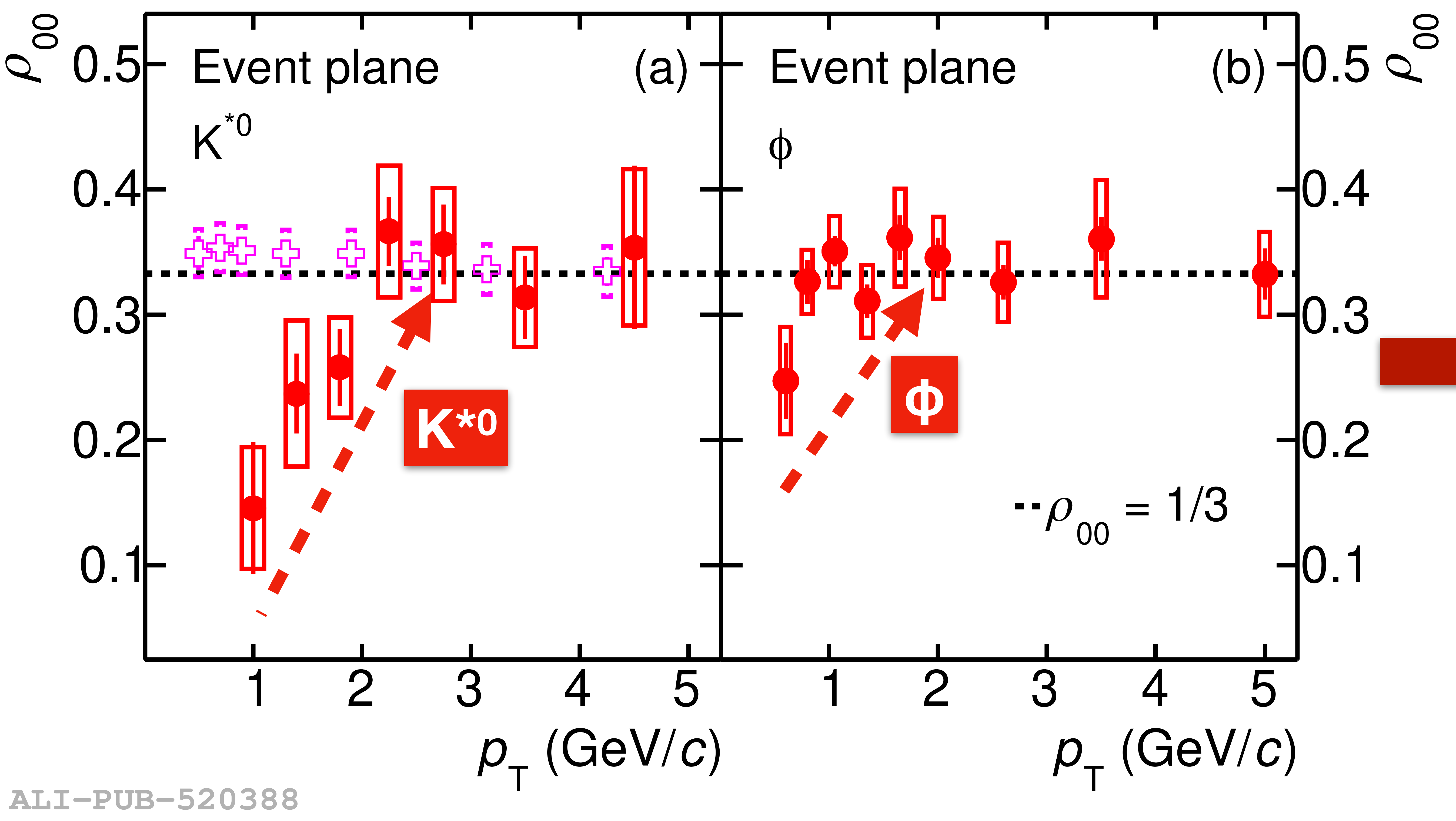
Prediction at heavy-quark sector

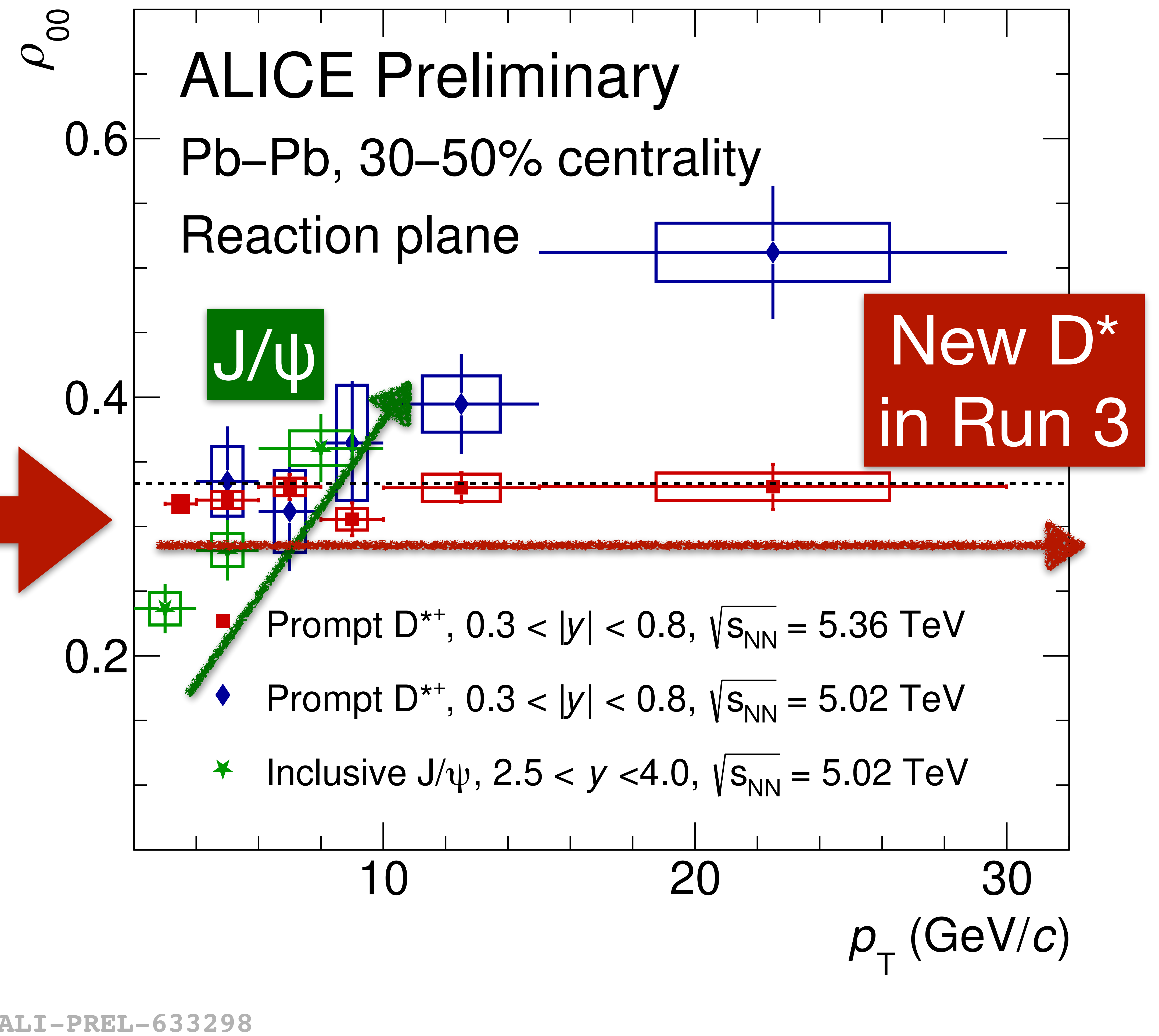


Would a similar trend show at heavy-quark sector?

Spin alignment of vector mesons

ALICE *Phys. Rev. Lett.* **125** (2020) 012301

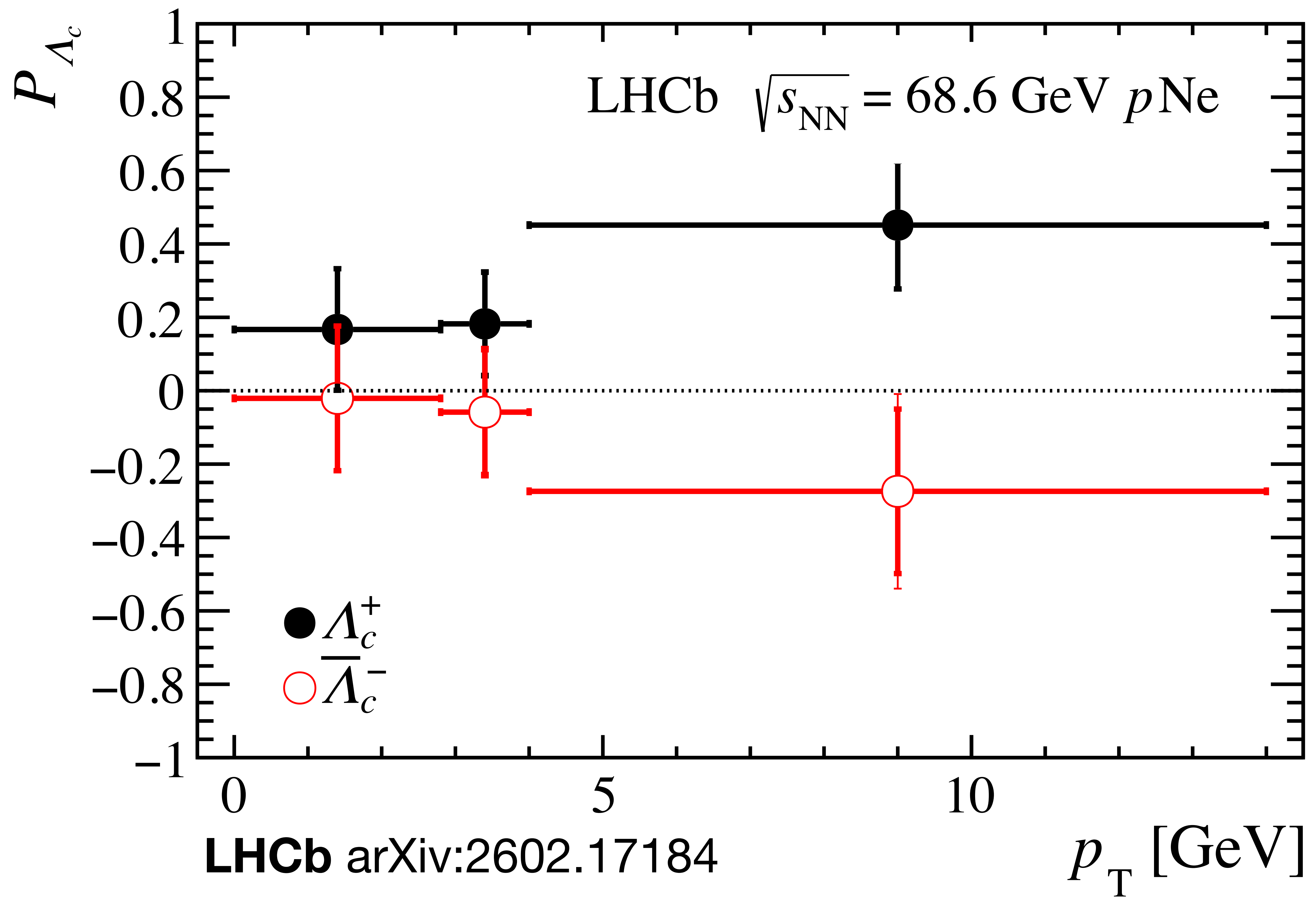




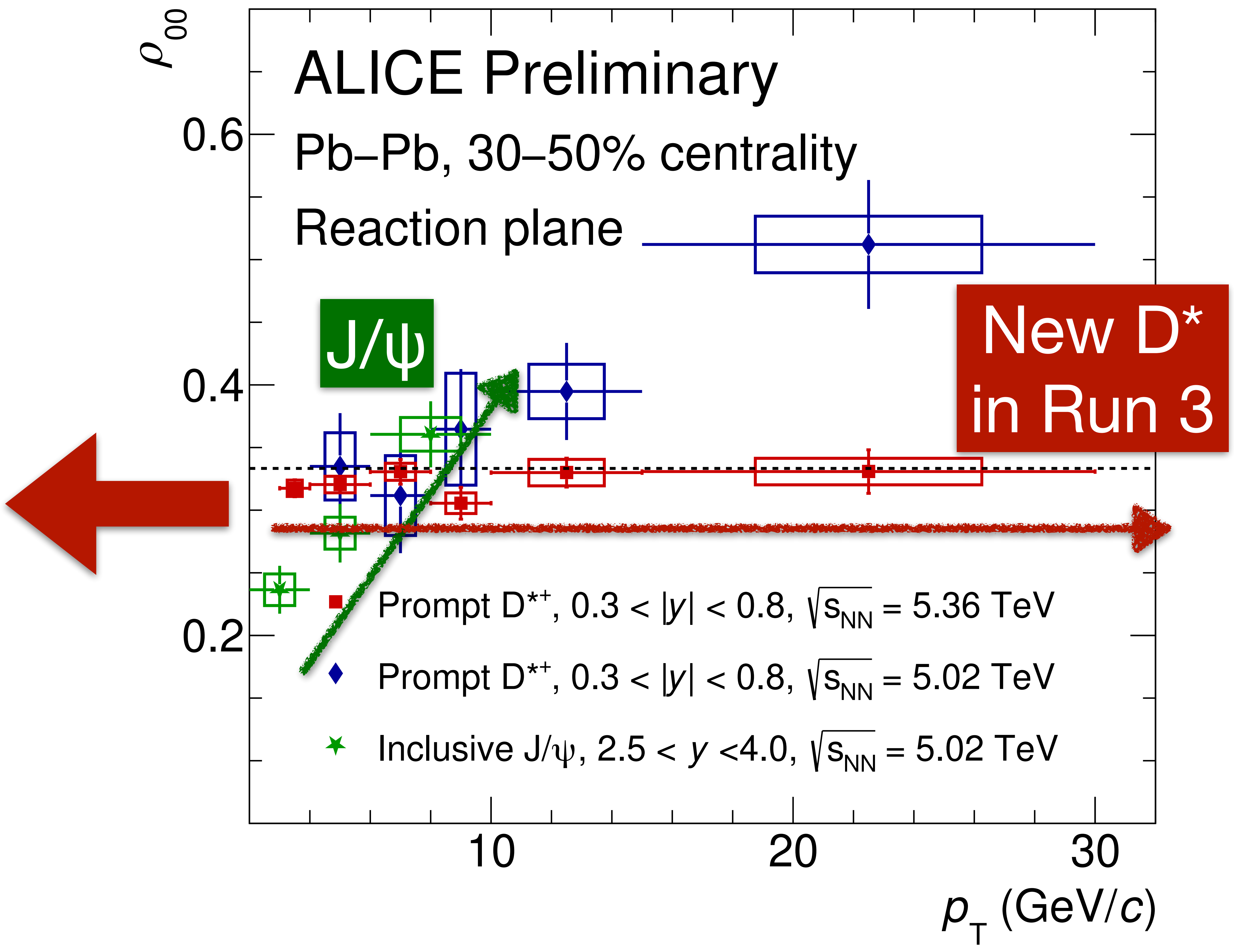
Not consistent with early direct extrapolation from Λ measurements

Charm quarks exhibit different spin alignment and polarization behaviors

Spin alignment of HF particles



LHCb arXiv:2602.17184



Λ_c^+ Evidence of x_F dependent polarization

Λ_c^- Polarization compatible with zero

First step towards understand charm baryon polarization mechanisms

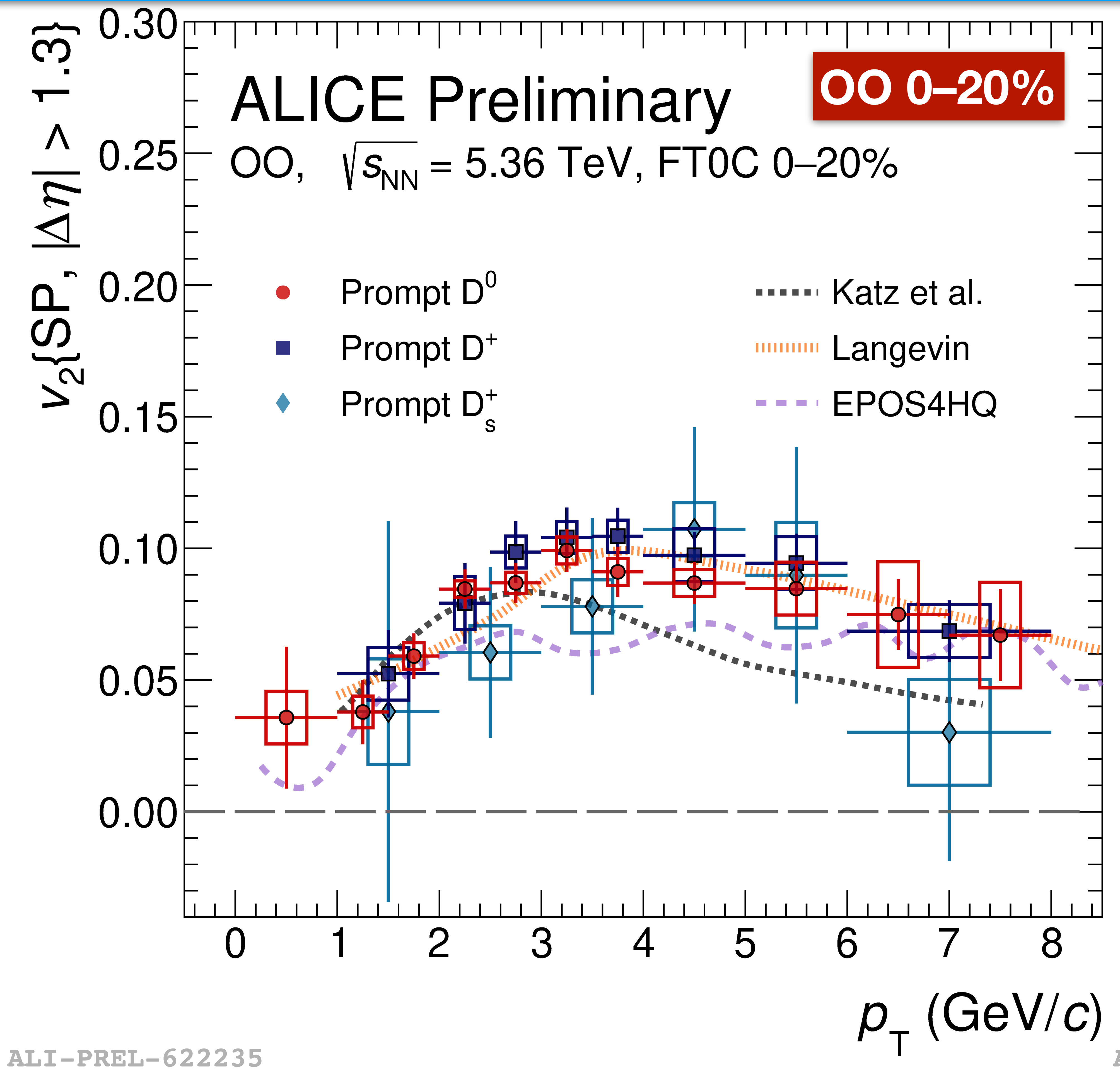
Charm quarks exhibit different spin alignment and polarization behaviors

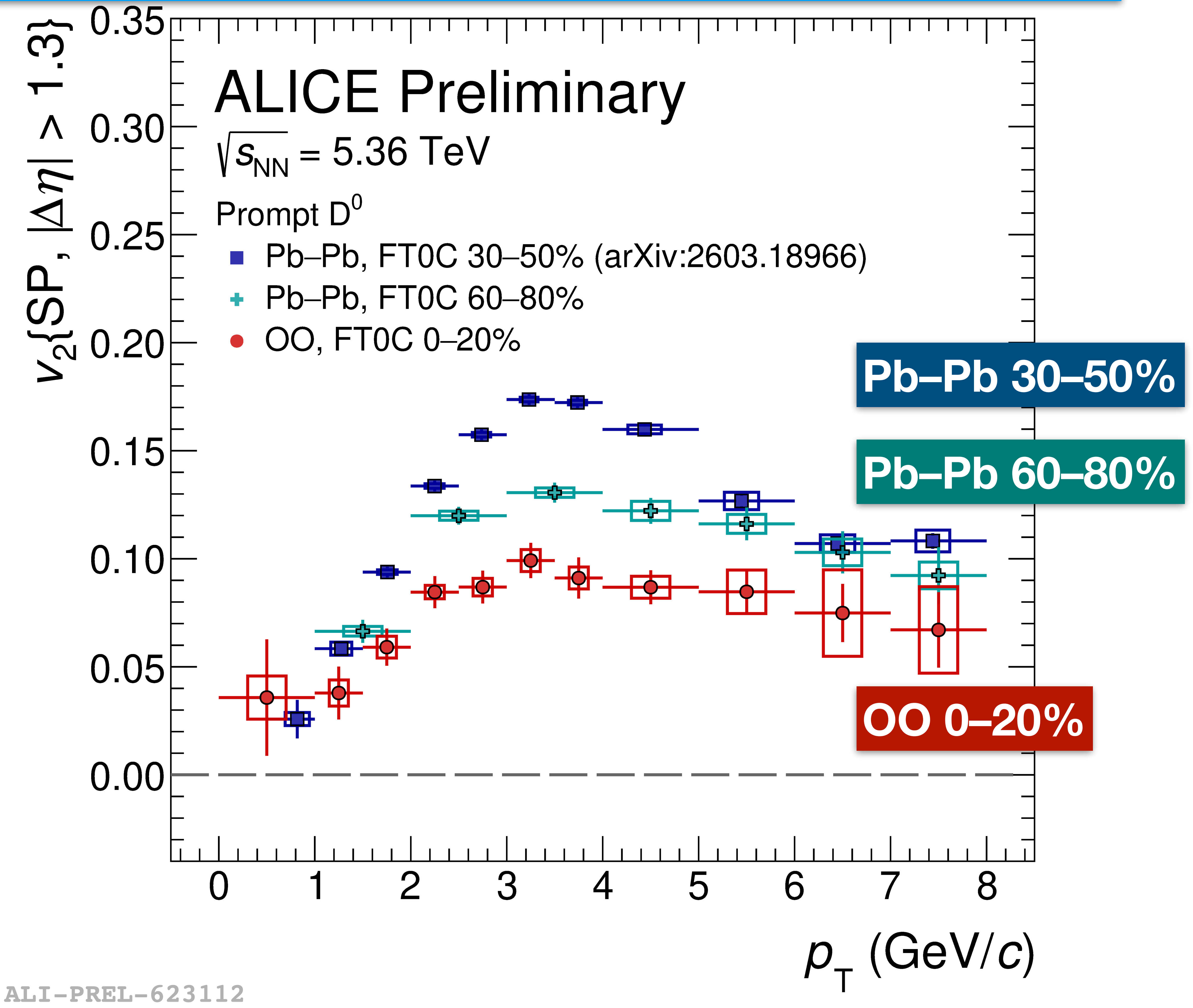
What do we learn?

- Do heavy quarks hadronization via coalescence in QGP?
  ➡ Sequential hadronization is favored
- What is the particle production mechanism across systems?
- What is the degree of thermalization of heavy quarks in QCD medium?
- What can we learn more from heavy quarks?
- Is there the dead-cone effect of medium-induced gluon radiation of heavy quarks?

Backup

D meson v_2 in OO collisions





- D meson v_2 in OO agrees with models including QGP formation
- Sizable differences between peripheral Pb–Pb and central OO
  - ➡ Similar multiplicity, but OO has smaller eccentricity