Open charm and beauty production and anisotropy from small to large systems with ALICE

Stefano Trogolo
CERN
on behalf of the ALICE Collaboration

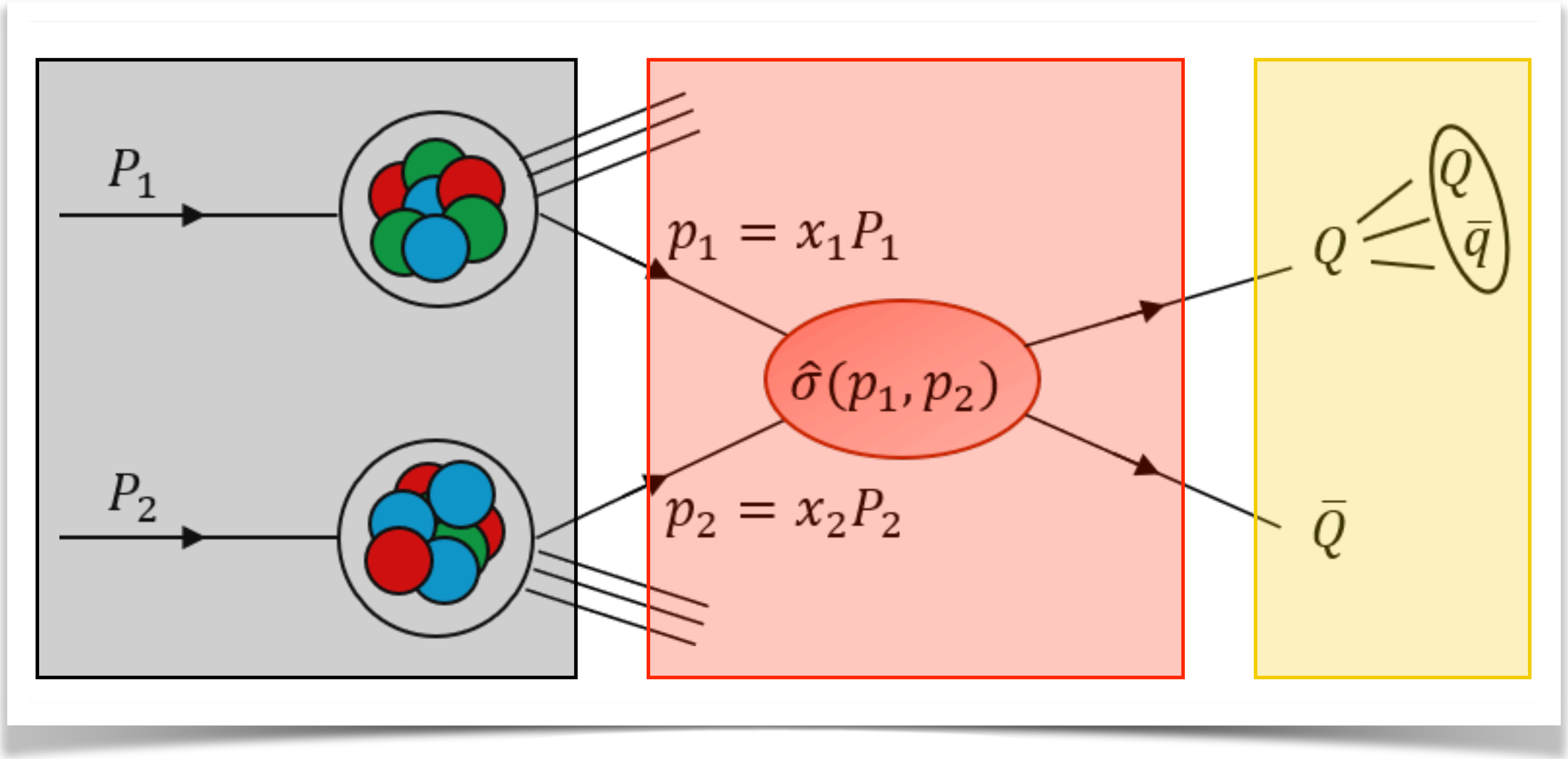
EPS-HEP Conference - 26-30 July 2021

Heavy-flavour production in pp collisions

- Heavy quarks produced in initial hard-scattering processes
- HF hadron production measurements → test of pQCD calculations

$$\frac{d\sigma^{H_c}}{dp_T}(\mu_F,\mu_R) = \mathrm{PDF}(x_1,\mu_F)\cdot \mathrm{PDF}(x_2,\mu_F) \otimes \frac{d\sigma^{c}}{dp_T^{c}}(x_1,x_2,\mu_F,\mu_R) \otimes D_{c\to H_c}(z = p_{H_c}/p_c,\mu_F)$$

Parton distribution functions (PDFs)	Hard scattering cross section (pQCD)	Fragmentation function (hadronisation)



- description in pp collisions based on factorisation theorem → fragmentation functions assumed universal and constrained from e^+e^-/ep measurements
- Ratios of particle species → sensitive to HF quark hadronisation

Heavy-flavour production in heavy-ion collisions

- Heavy quarks → probes to investigate the properties of the quark-gluon plasma (QGP)
  - ➡ Production time of $c\bar{c}(b\bar{b})$ pair at rest $t_{prod} \simeq \hbar/2m_{c(b)} \simeq 0.07(0.02)$ fm/c
  - ➡ QGP formation time $t_{QGP} \simeq 0.1\text{-}1$ fm/c [1]

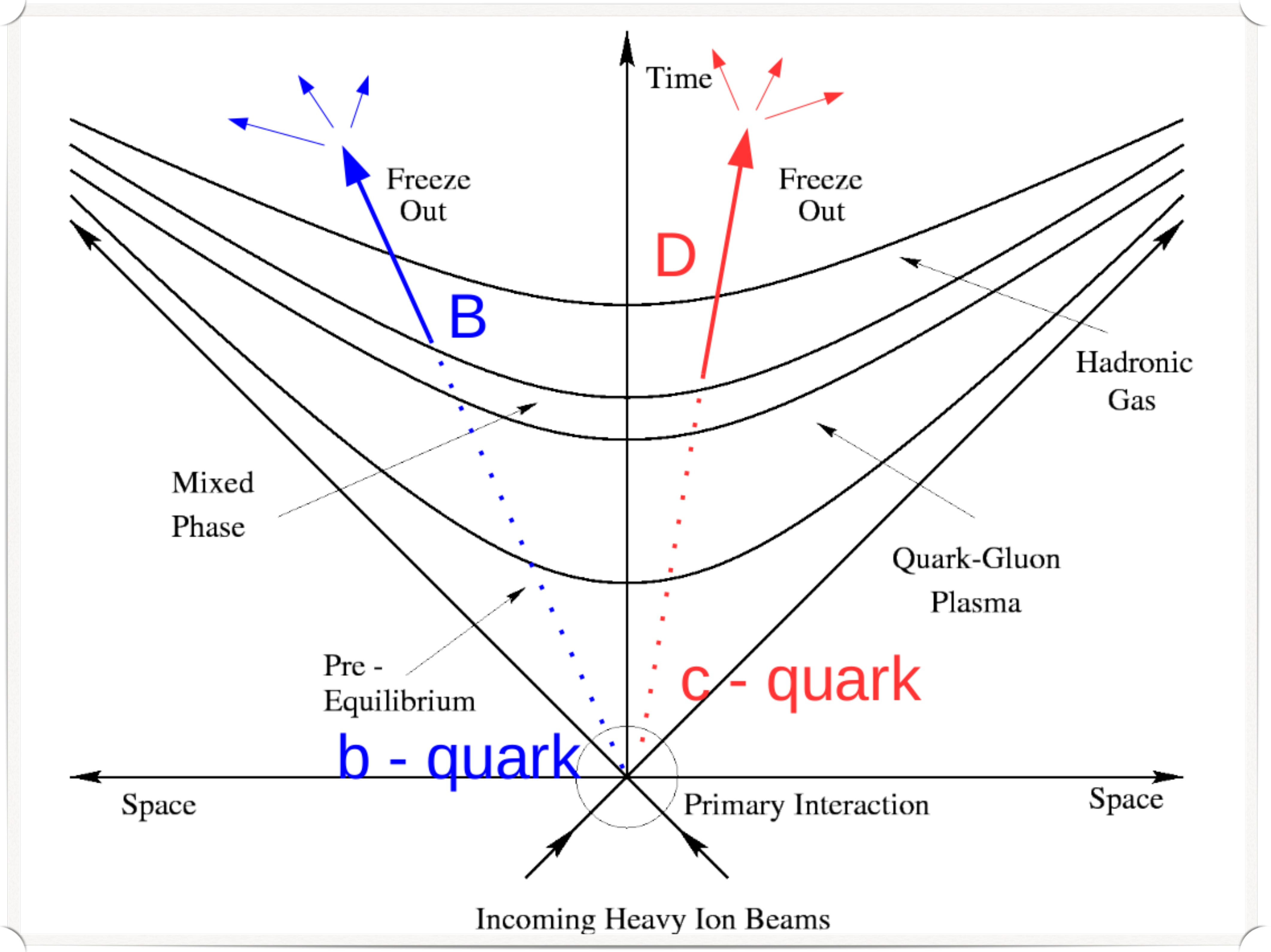
[1] F. M. Liu, S. X. Liu, Phys. Rev. C 89, 034906 (2014)

- In-medium parton energy loss via elastic scattering and gluon radiation
  - ➡ *quark mass and colour-charge dependencies*
- Hydrodynamical expansion of the medium
  - ➡ *collective motion, HQ thermalisation, path-length dependence of HQ energy loss*
- Nuclear modification factor

$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T}$$

- Azimuthal anisotropies

$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left\{1 + \sum_{i=1}^{\infty} v_n \cos[n(\varphi - \Psi_n)]\right\} \longrightarrow \text{Flow harmonic coefficient: } v_n = \langle \cos[n(\varphi - \Psi_n)] \rangle$$



The ALICE experiment

Time Projection Chamber

- Track reconstruction
- Particle identification via specific energy loss

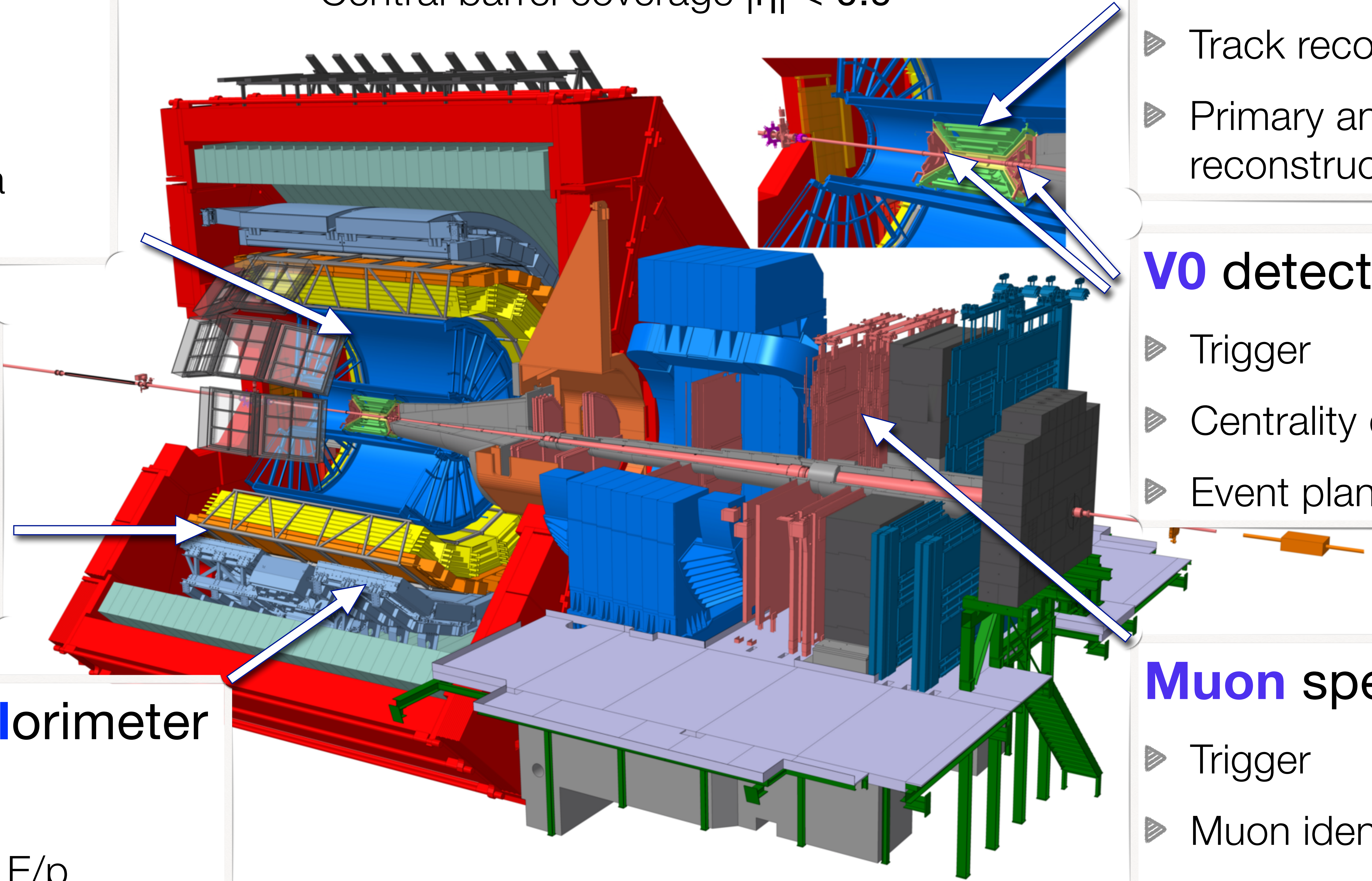
Time of Flight detector

- Particle identification via the time-of-flight measurement

ElectroMagnetic Calorimeter

- Trigger
- Particle identification via E/p measurement

Central barrel coverage $|\eta| < 0.9$



Muon spectrometer coverage $-4 < \eta < -2.5$

Inner Tracking System

- Track reconstruction
- Primary and decay vertex reconstruction

V0 detector

- Trigger
- Centrality determination
- Event plane estimation

Muon spectrometer

- Trigger
- Muon identification
- Track reconstruction

Leptons from HF-hadron decays

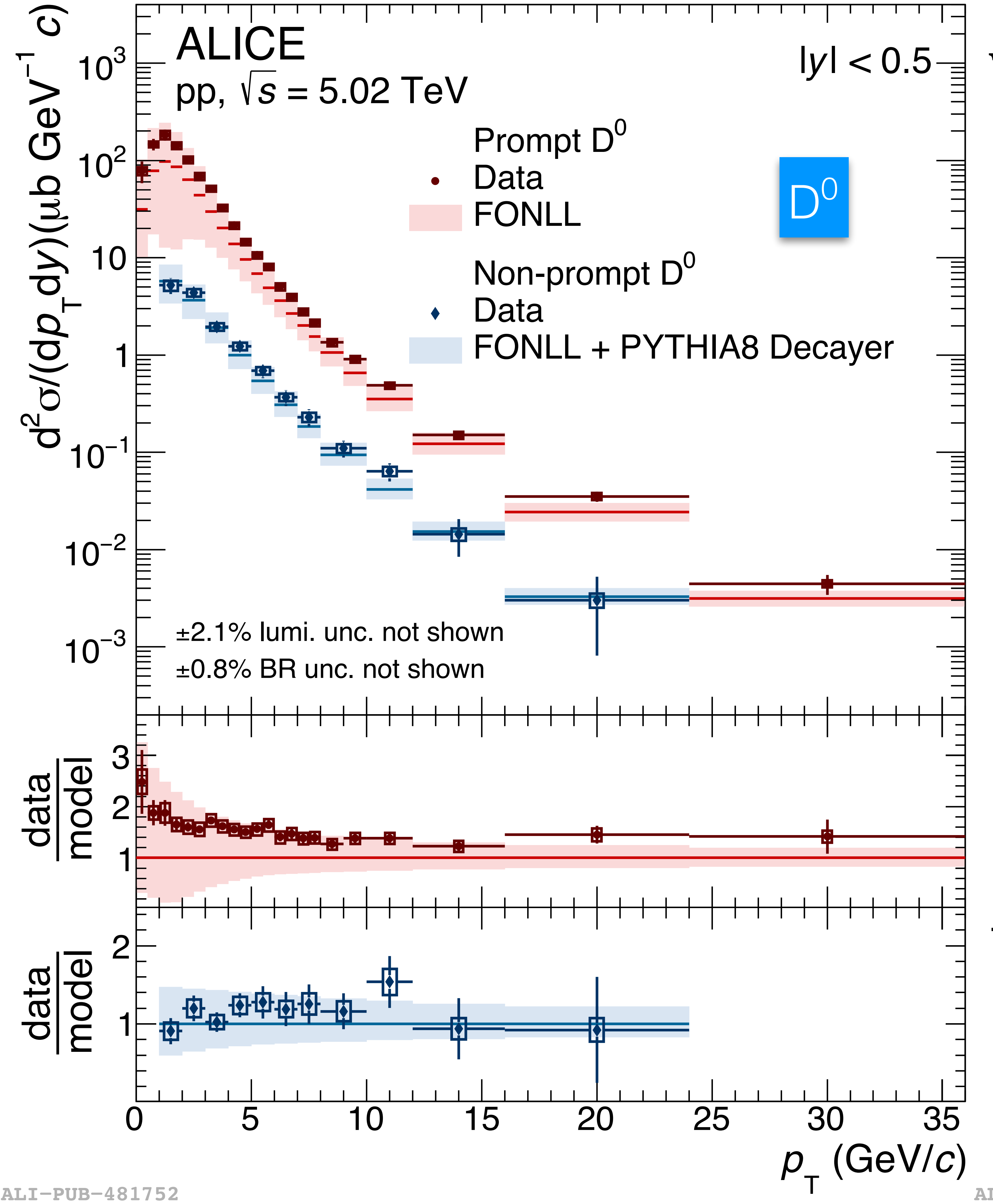
📖 ALICE, PLB 804 (2020) 135377

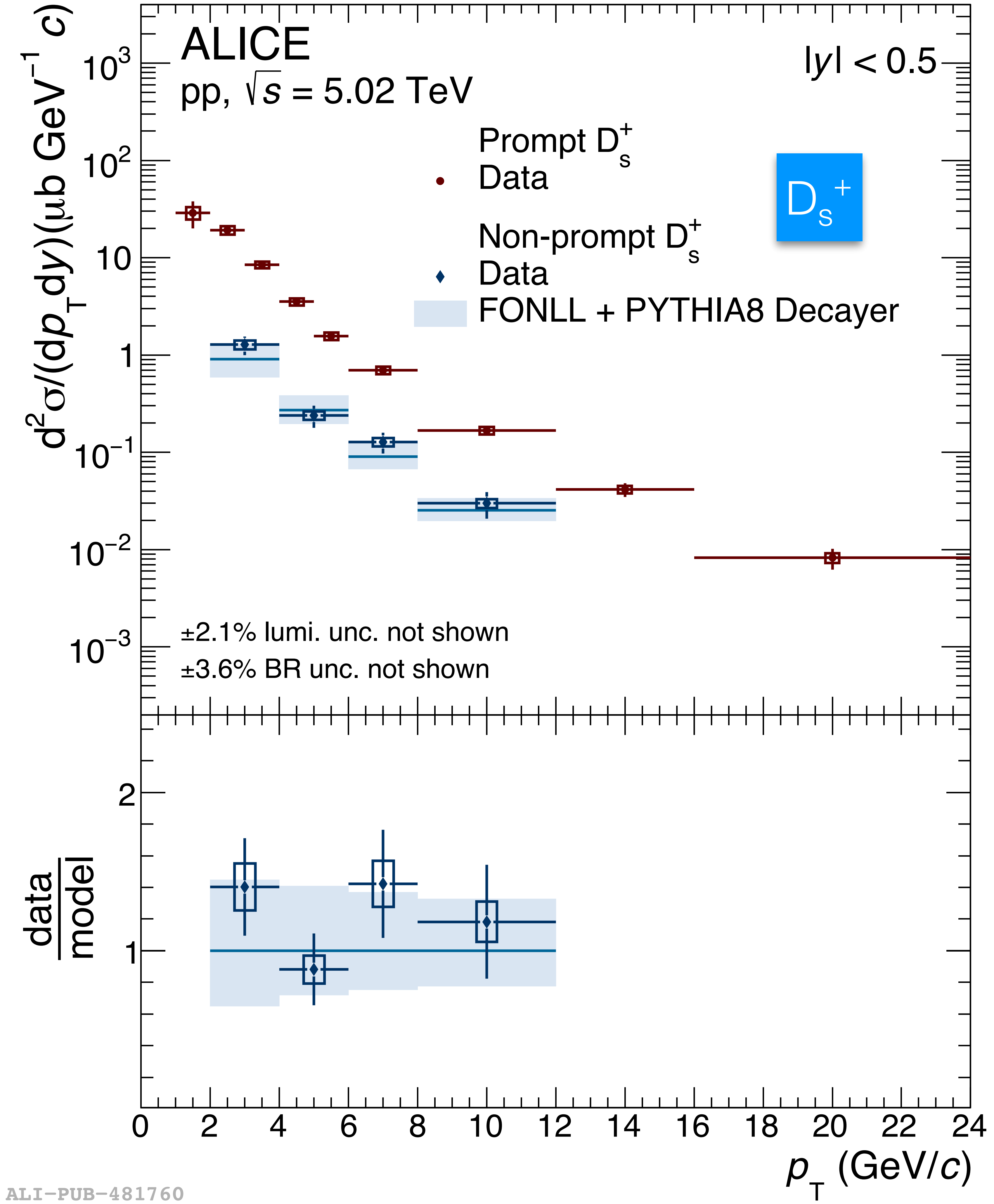
- Measured cross sections and beauty fraction described by FONLL calculations
  - $p_T < 5$ GeV/c: c,b→e results lie on upper edge of FONLL
  - $p_T > 5$ GeV/c: semileptonic b-hadron decays (b→e) dominate and measurements still on the upper edge closer to FONLL mean value

Prompt and non-prompt D mesons

📖 ALICE, JHEP 05 (2021) 220

$\sqrt{s}$ = 5.02 TeV





- Prompt D mesons
  - ➡ **non-strange D** results lie on upper edge of FONLL
  - ➡ not available for D_s^+
- Non-prompt D mesons
  - ➡ in agreement with FONLL+PYTHIA8

More on charm baryons in…

"Charm cross section and fragmentation fractions in pp collisions with ALICE"

Luigi Dello Stritto

27th July, h 10:15

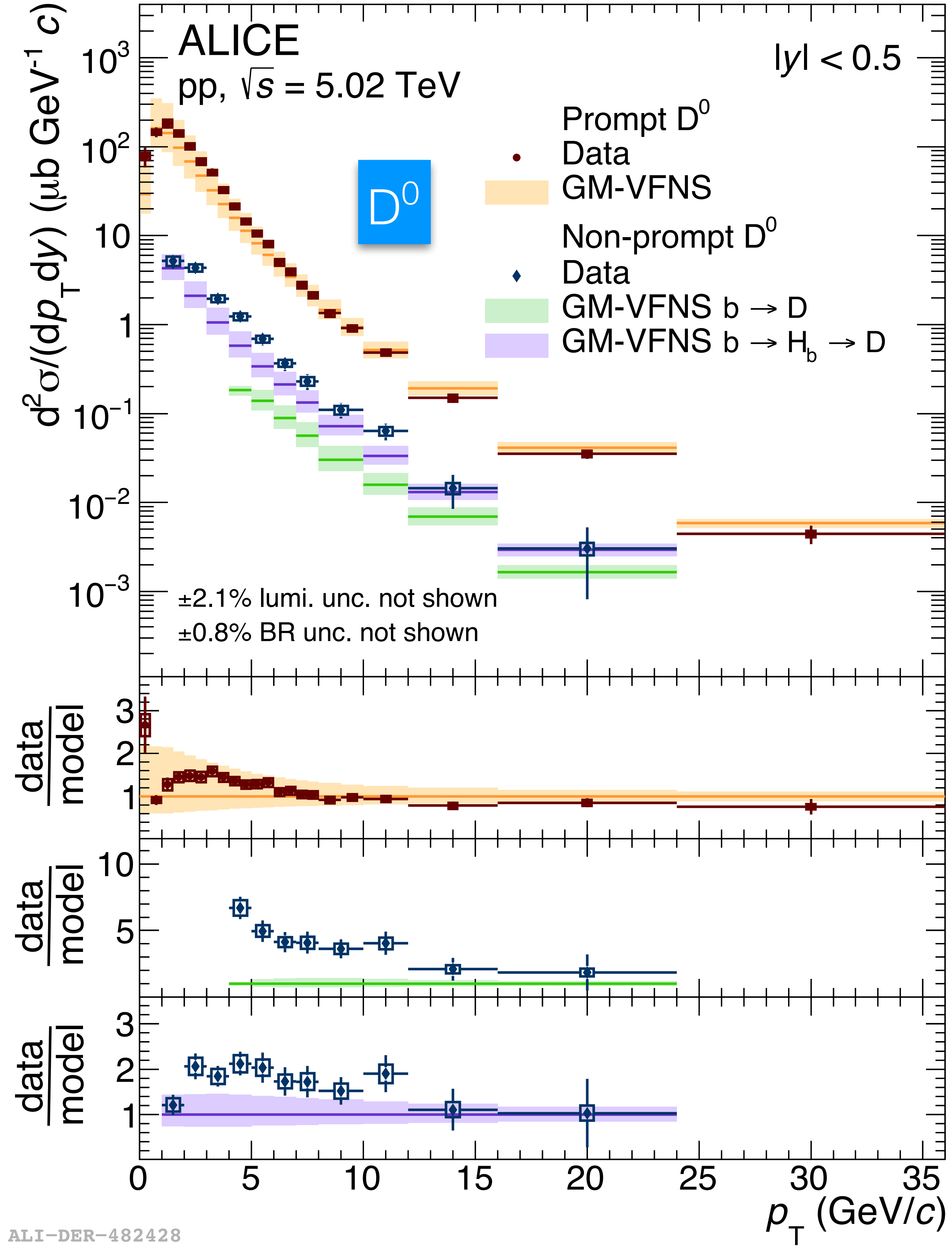
📖 FONLL: M. Cacciari et al. JHEP 1210 137 (2012)

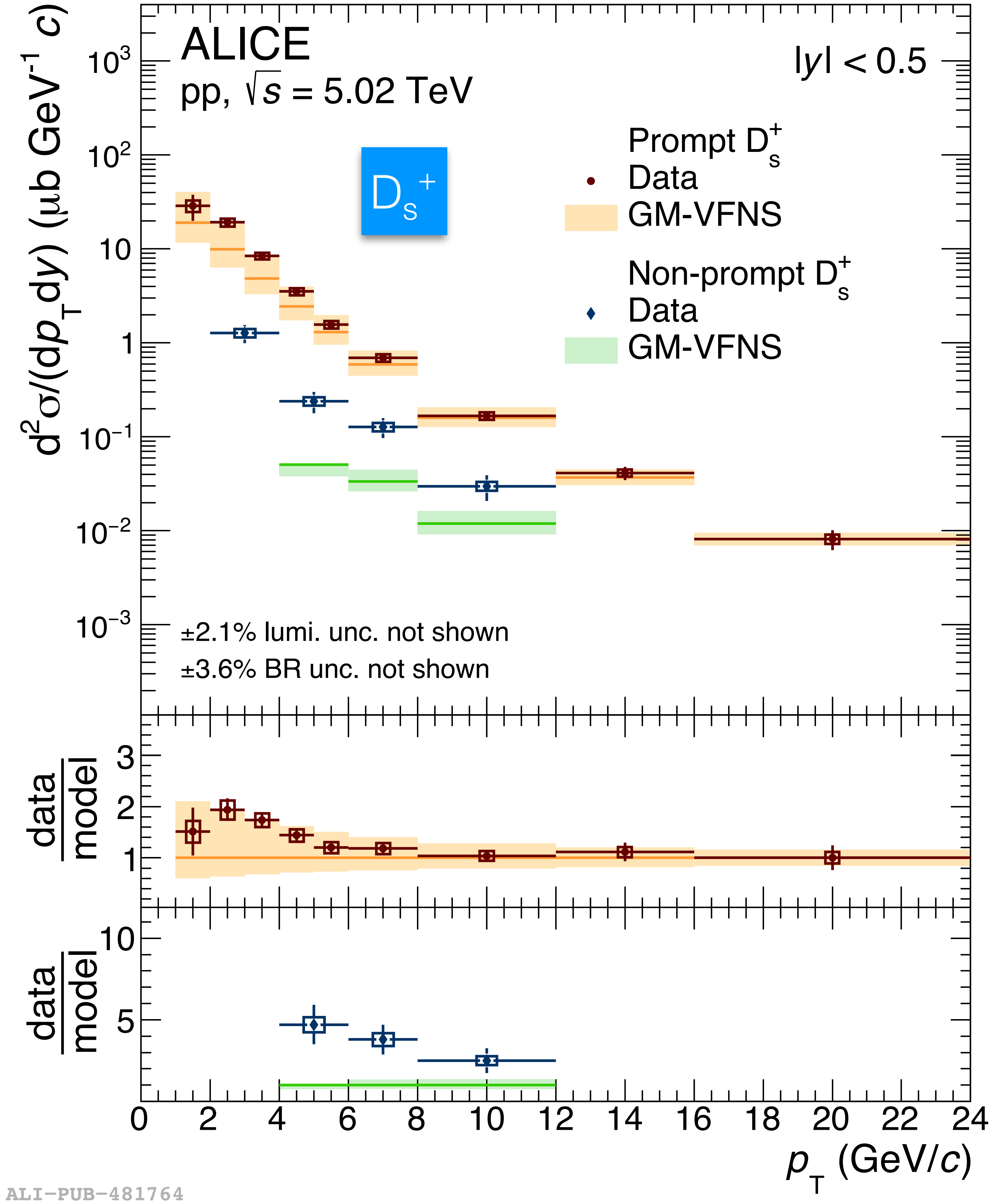
📖 PYTHIA8: T. Sjöstrand et al. JHEP 05 026 (2006)

Prompt and non-prompt D mesons

📖 ALICE, JHEP 05 (2021) 220

$\sqrt{s}$ = 5.02 TeV





- Prompt D mesons
  - ➡ measurements described within uncertainties
- Non-prompt D mesons
  - ➡ results are **underestimated**

GM-VFNS

non-prompt D^0, D^+ → *"two steps"*:
b→H_b and then H_b→D+X decay

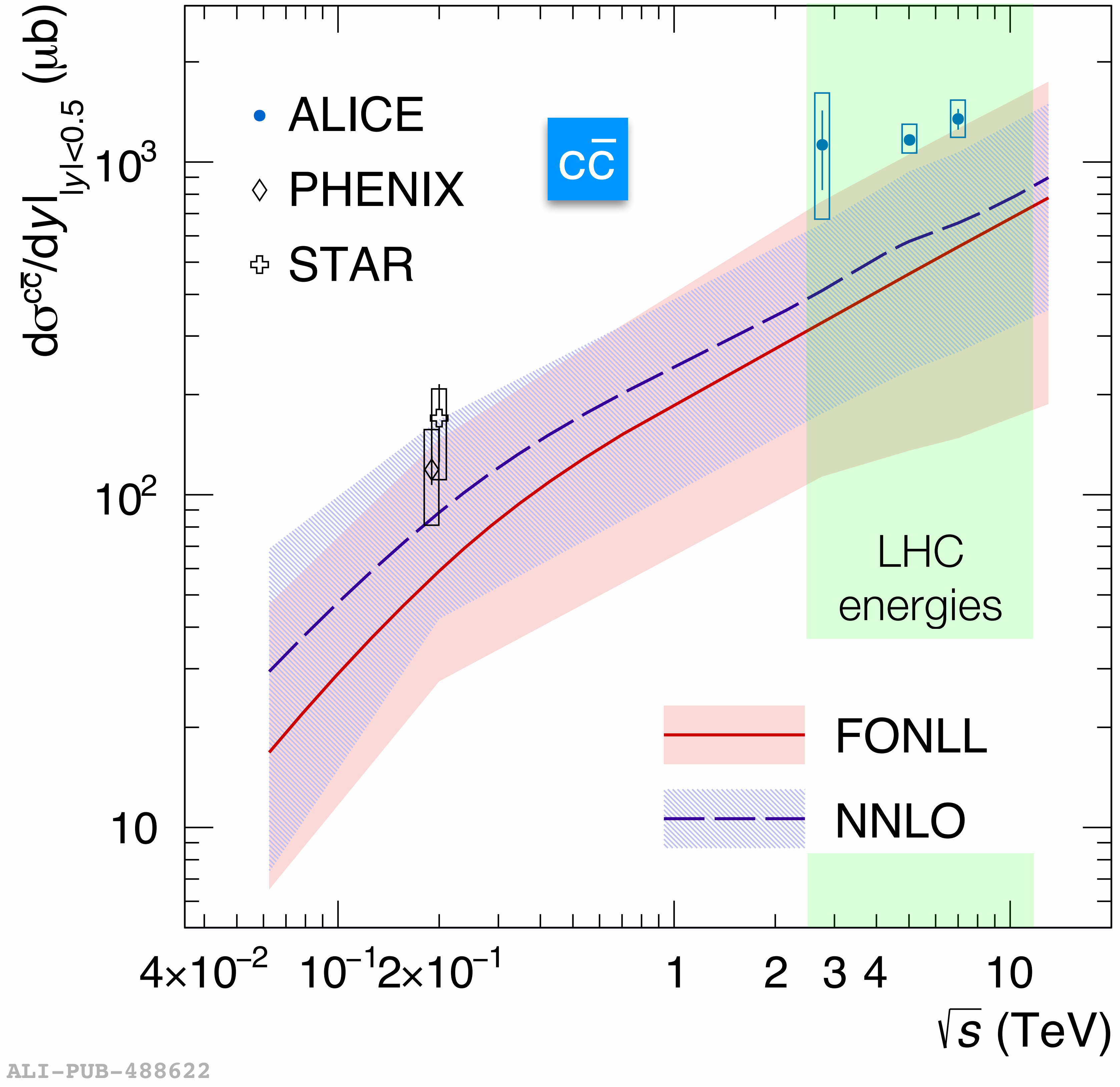
non-prompt D_s^+ → *"single step"*:
b→D_s^++X using FFs from e^+e^-

📖 GM-VFNS: G. Kramer et al, Nucl. Phys. B 925 415-430 (2017)

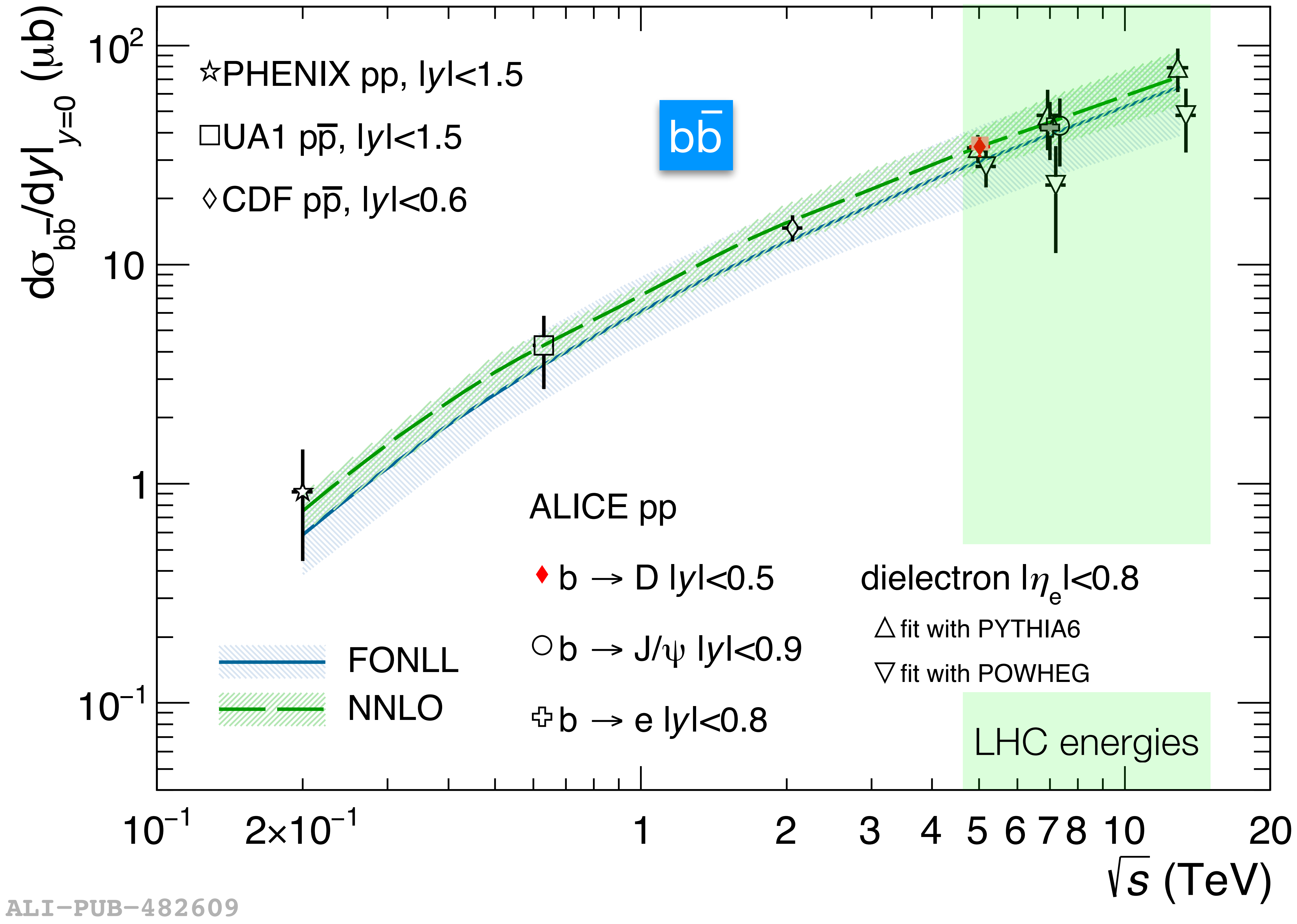
📖 GM-VFNS: T. Kneesch et al. Nucl. Phys. B 799 34-59 (2008)

$c\bar{c}$ and $b\bar{b}$ cross section in pp collisions

📖 ALICE, arXiv:2105.06335



📖 ALICE, JHEP 05 (2021) 220



$\sqrt{s}$ = 5.02 TeV

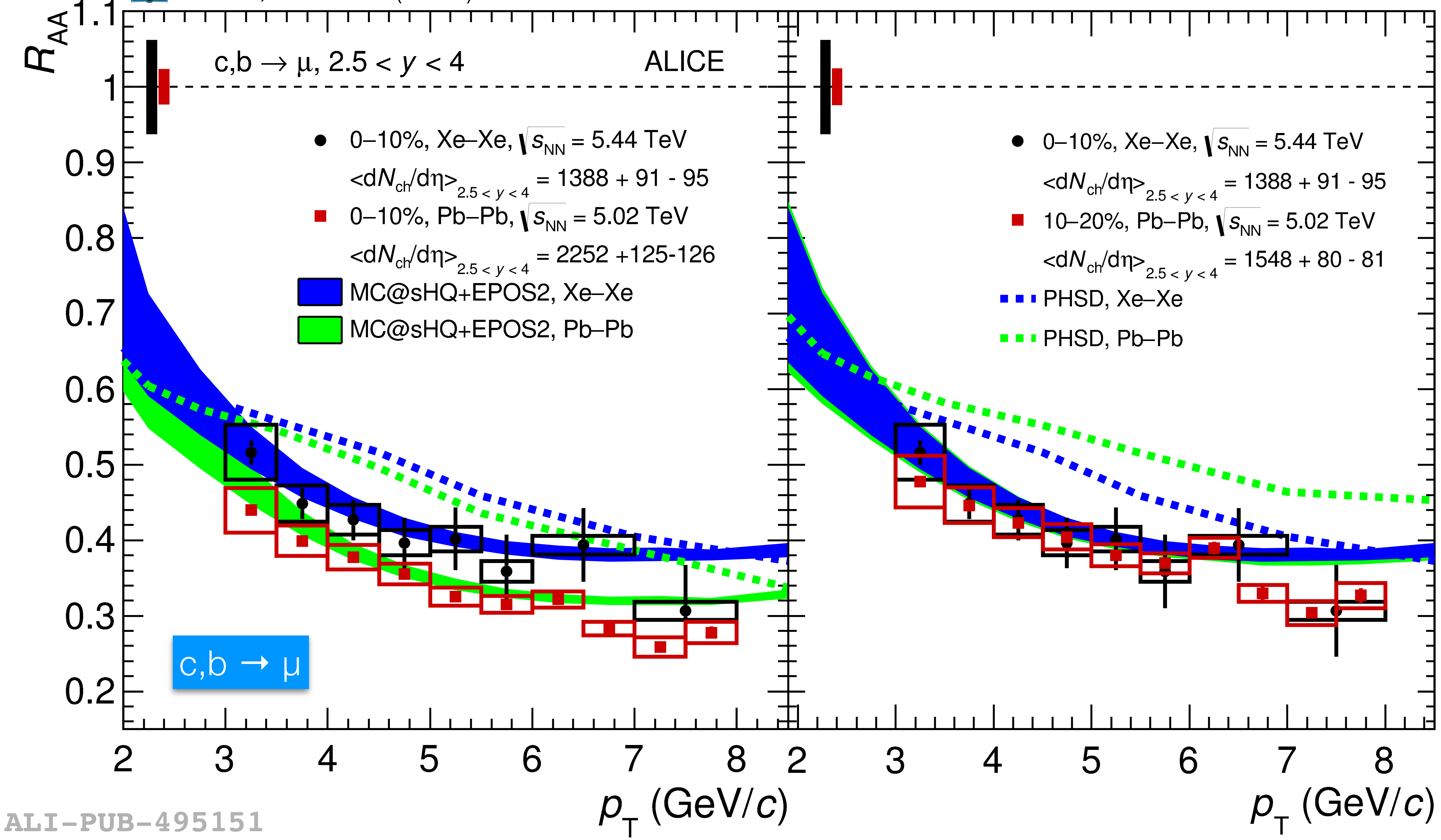
📖 FONLL: M. Cacciari et al. JHEP 1210 137 (2012)

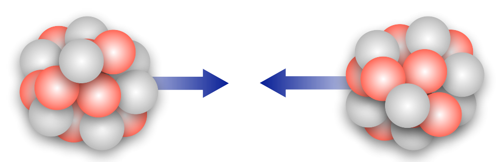
📖 NNLO: S. Catani et al. JHEP 03 (2021) 029

- $c\bar{c}$ cross section at 5.02 TeV with latest measurements of the charm mesons and baryons
- Most precise measurement of $b\bar{b}$ cross section at 5.02 TeV with non-prompt D mesons
  - ➡ **most precise** results at midrapidity using **machine learning techniques**
- Measurements described by FONLL and NNLO calculations

Muons from heavy-flavour hadrons

ALICE, PLB 819 (2021) 136437





Pb–Pb $\sqrt{s_{NN}}$ = 5.02 TeV

Xe–Xe $\sqrt{s_{NN}}$ = 5.44 TeV

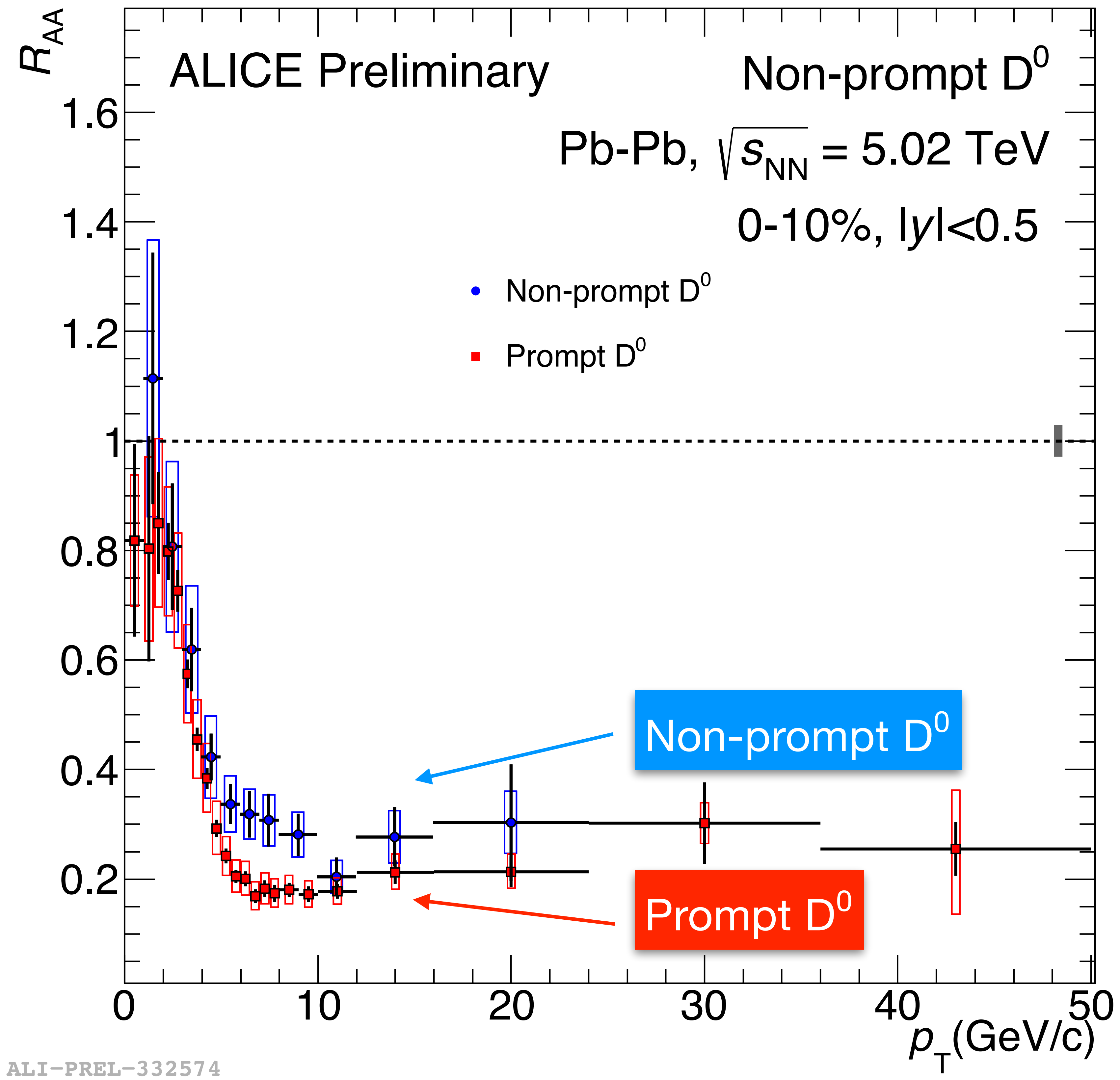
- R_{AA} of muons from heavy-flavour hadron decays
- Comparison with model predictions
  - ➡ only **collisional energy loss** overestimates the R_{AA}
  - ➡ results well described by models with both collisional and radiative energy loss

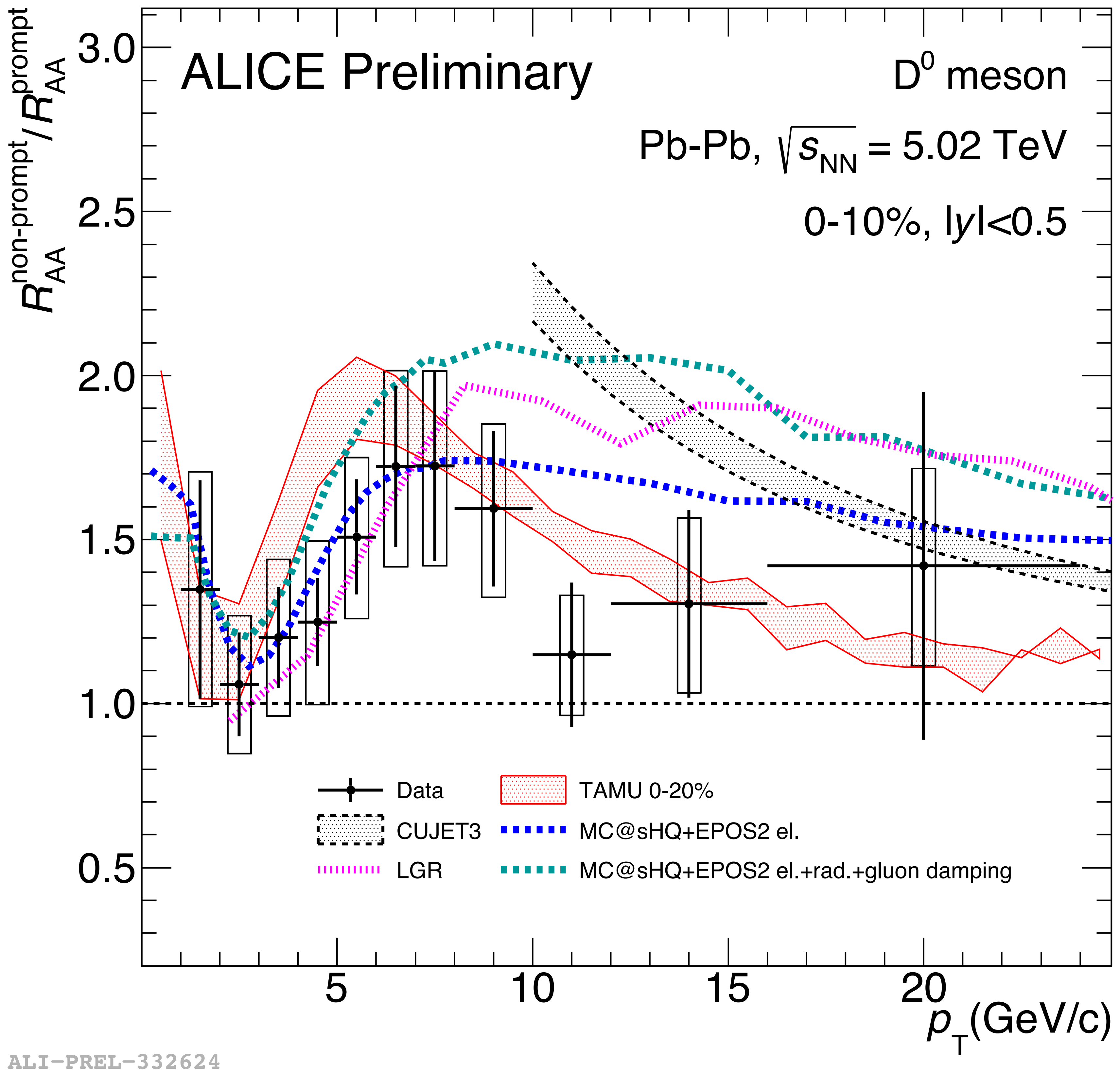
- Similar R_{AA} for **HF → μ** in Pb–Pb and Xe–Xe collisions at similar $\langle dN_{ch}/d\eta \rangle$
  - ➡ possibility to further constrain model calculations

MC@sHQ+EPOS: PRC 89, 014905 (2014)   PHSD: PRC 93, 034906 (2016)

Prompt/non-prompt D^0 meson in Pb-Pb collisions

Pb–Pb $\sqrt{s_{NN}}$ = 5.02 TeV



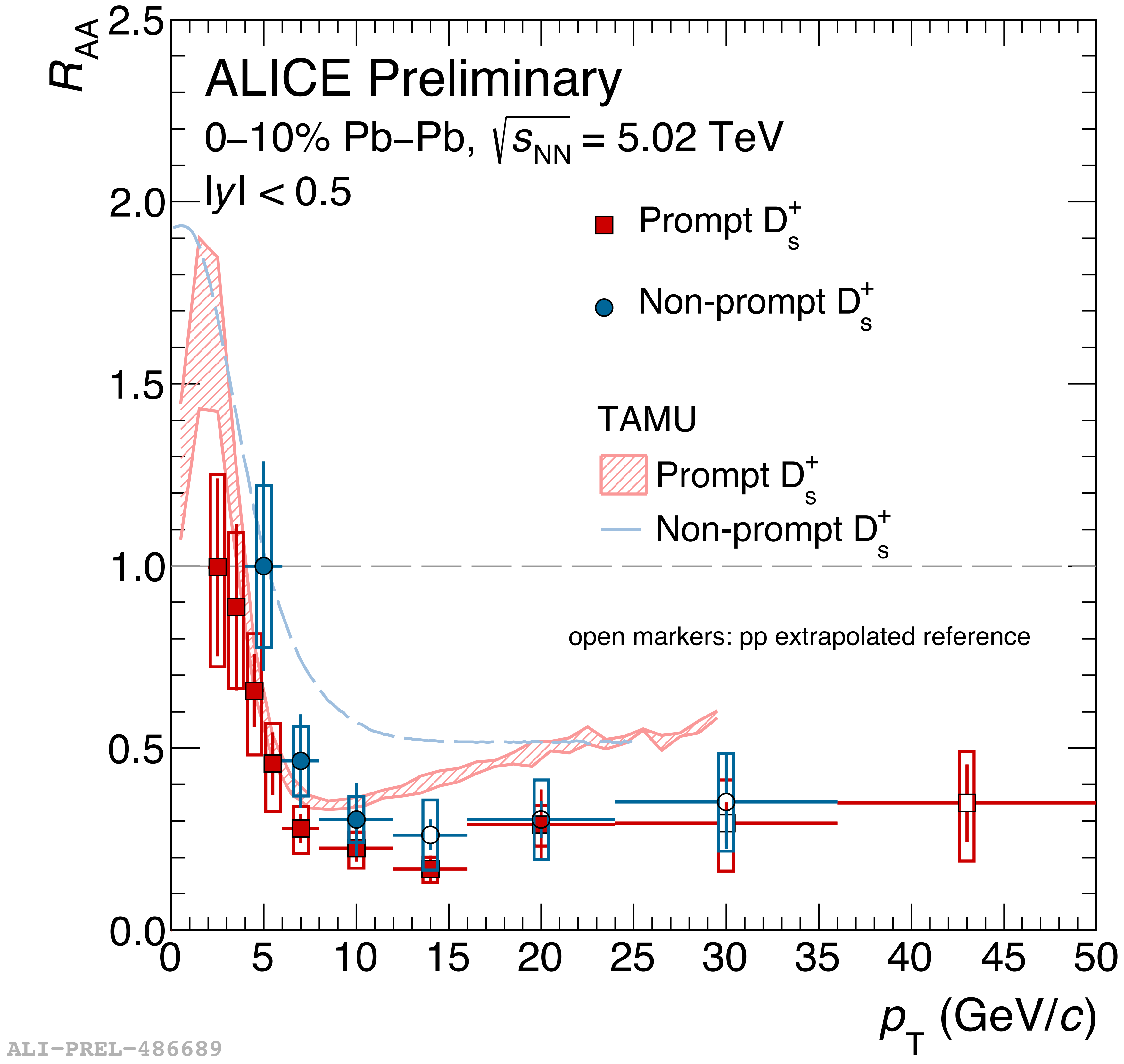


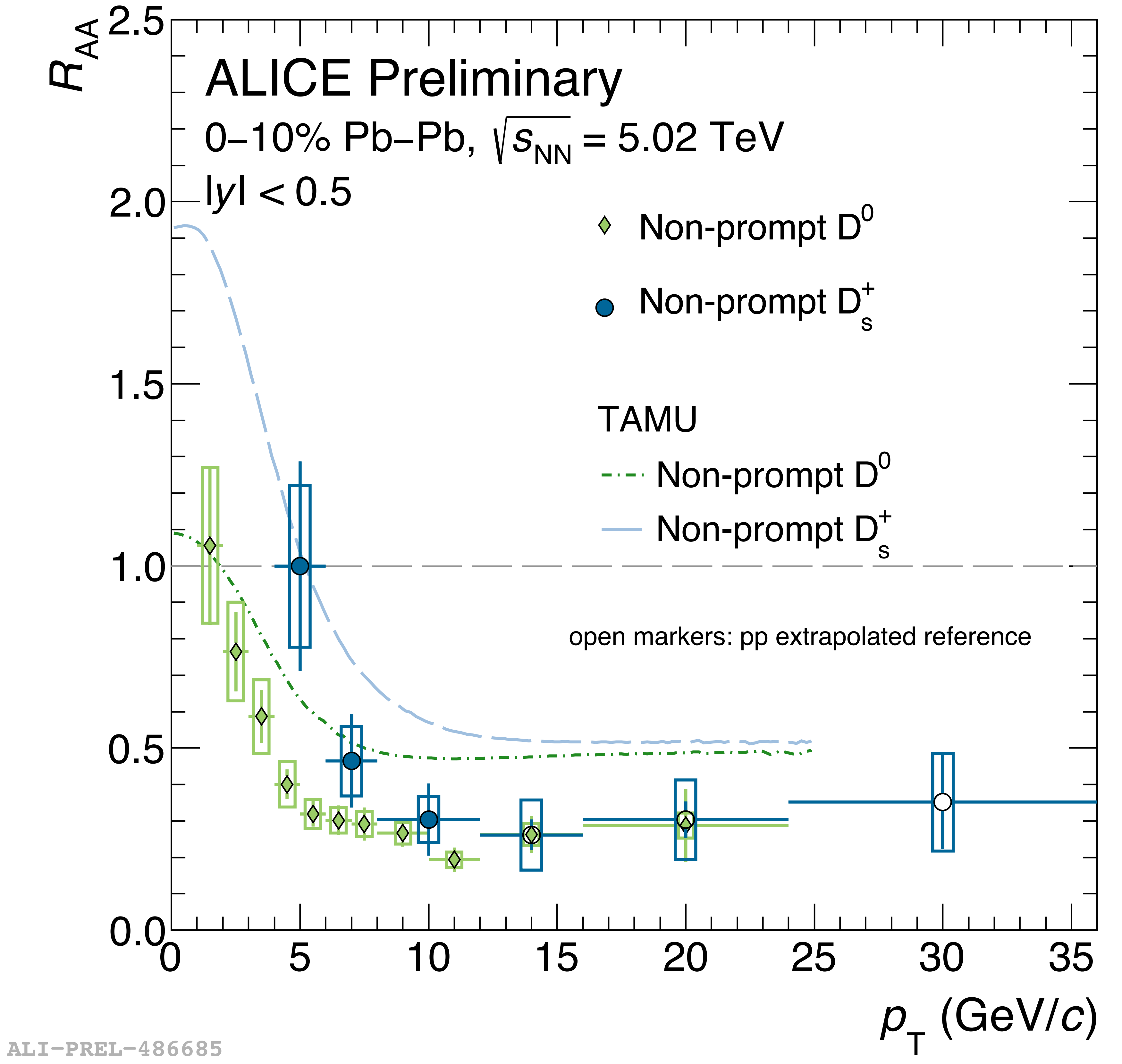
- Prompt D^0 R_{AA} down to $p_T = 0$ for the first time in heavy-ion collisions
- R_{AA} (non-prompt) ≥ R_{AA} (prompt)
  - ➡ hint of $\Delta E_c > \Delta E_b$ → dead-cone effect (i.e. *gluon radiation suppressed for small angles* $\theta < m/E$)

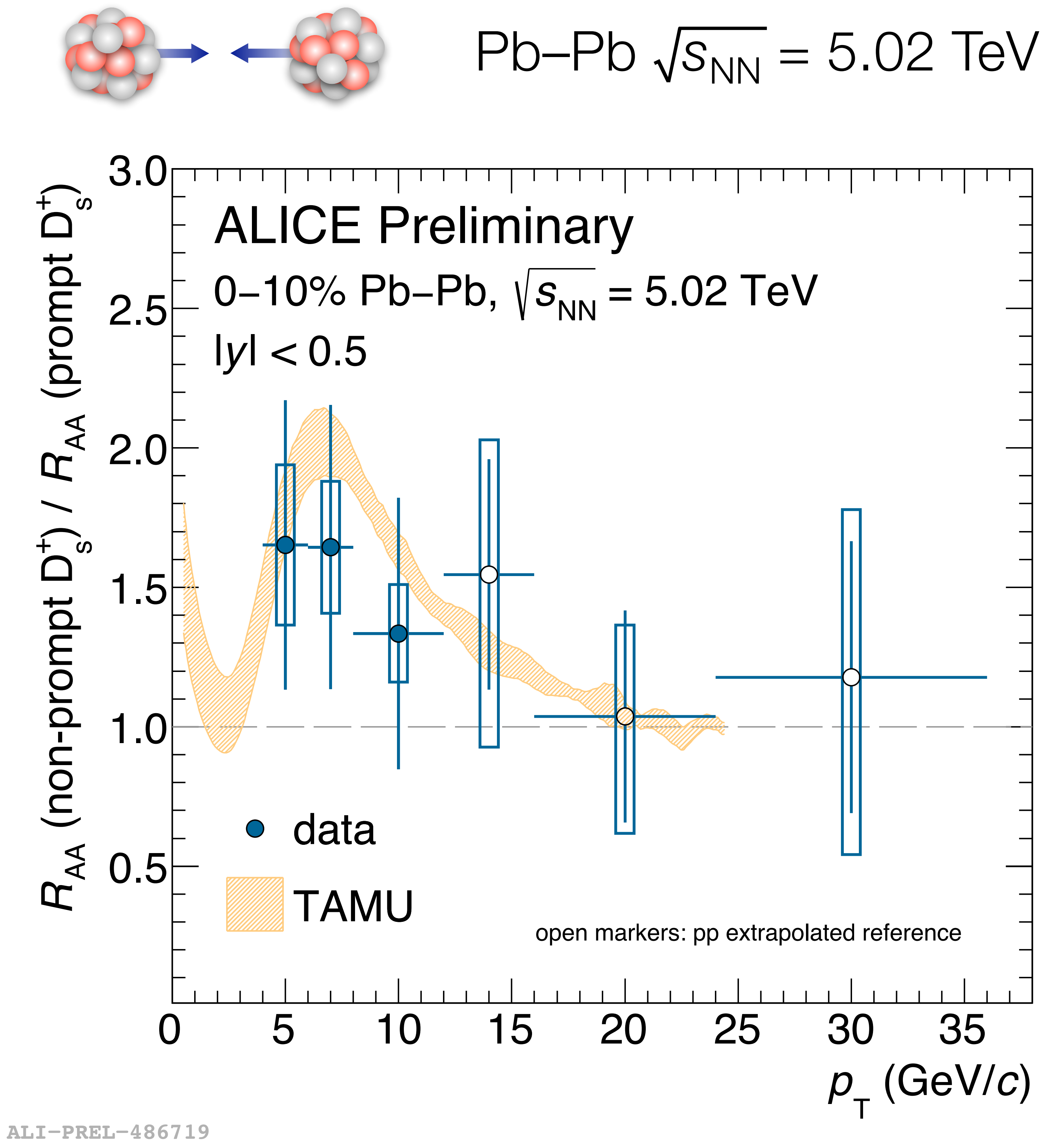
- R_{AA} (non-prompt)/R_{AA} (prompt) compared with theoretical models
  - ➡ depletion at low p_T → mostly driven by charm quark coalescence

MC@sHQ+EPOS: PRC 89, 014905 (2014)
TAMU: PLB 735 (2014) 445-450
CUJET3: Chin.Phys.C 43, (2019) 044101
LGR: EPJC 80 (2020) 1113

Prompt/non-prompt D_s^+ meson in Pb-Pb collisions



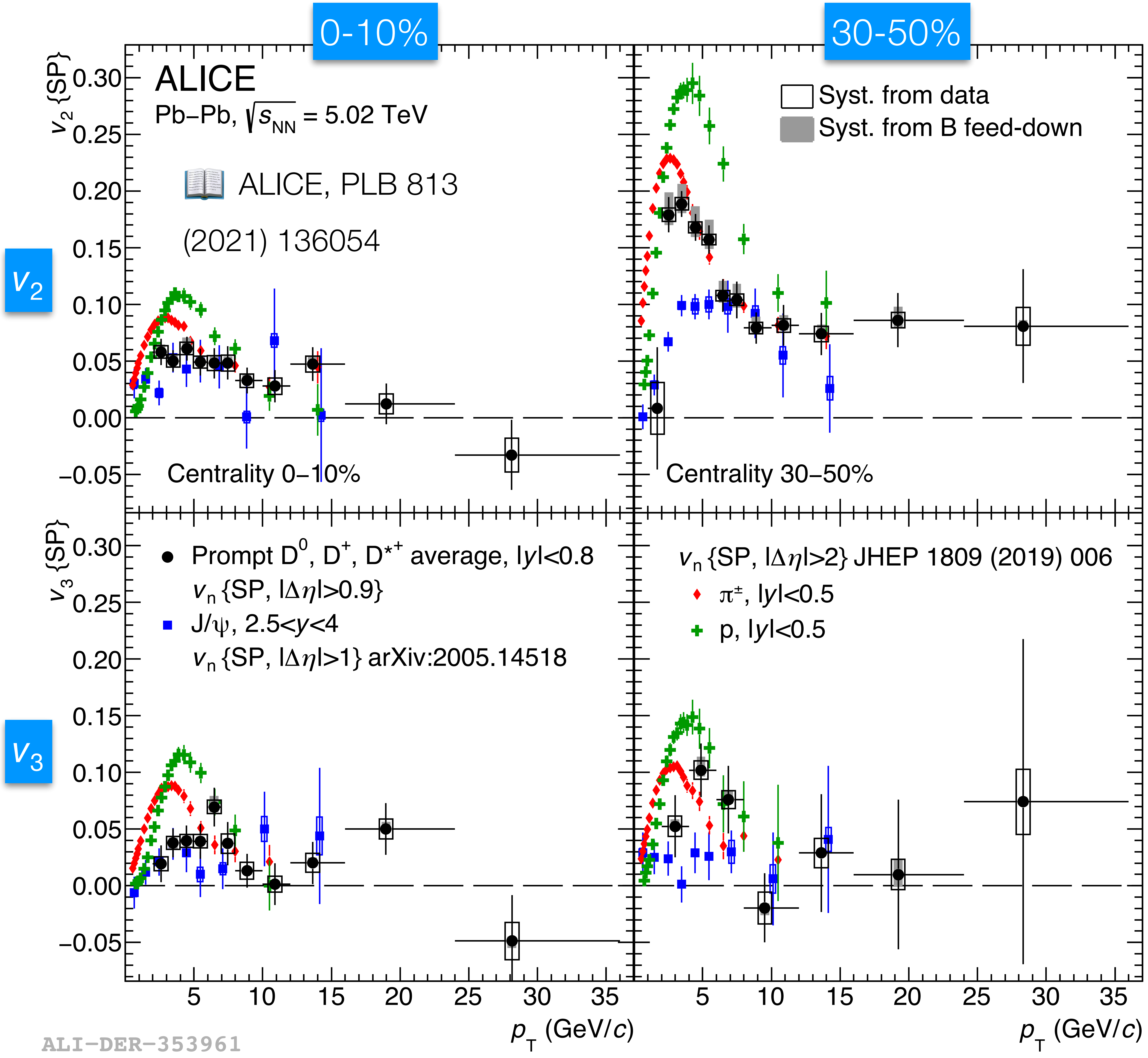




- **First measurement** of non-prompt D_s^+ R_{AA} in central (0-10%) heavy-ion collisions
- Hint of larger R_{AA} than **prompt D_s^+** and **non-prompt D^0** mesons in the low p_T region
  - ➡ described by TAMU model predictions
  - ➡ interplay of **charm and beauty energy loss** and **recombination** in the medium

TAMU: PLB 735 (2014) 445-450

Anisotropic flow of heavy-flavour hadrons

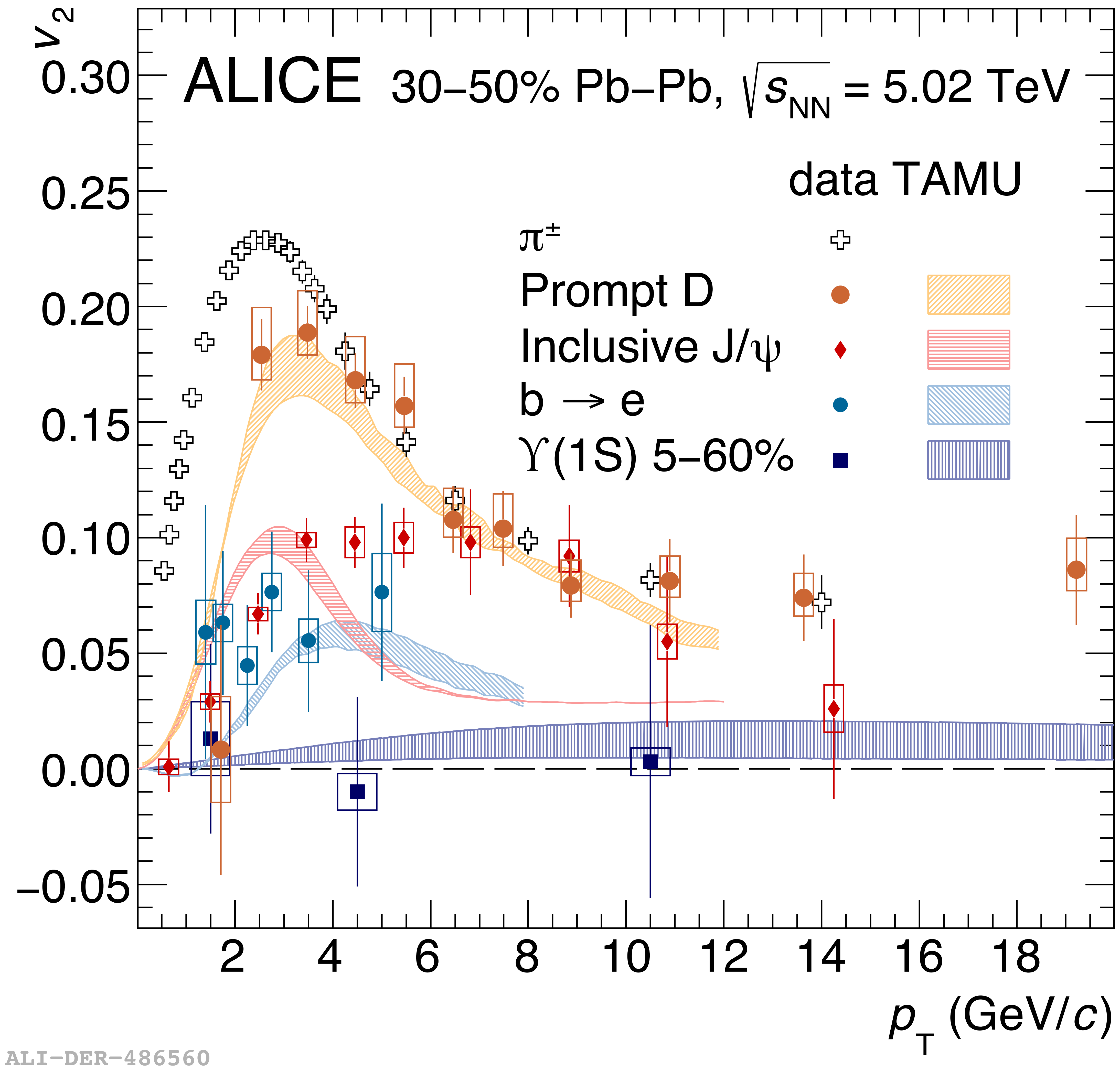


📖 $\pi^{\pm}$,p: JHEP 1809 (2018) 006 📖 J/ψ: JHEP 10 (2020) 141

Pb–Pb $\sqrt{s_{NN}}$ = 5.02 TeV

- Significant v_n coefficients for open and hidden charm
  - ➡ v_2 → participation to collective motion
  - ➡ v_3 → initial state event-by-event fluctuations
- p_T < 3-4 GeV/c: mass hierarchy
  - ➡ $v_n(J/\psi) < v_n(D) < v_n(p) < v_n(\pi)$
- 3-4 < p_T < 6-8 GeV/c: n-quark scaling and coalescence
  - ➡ $v_n(J/\psi) < v_n(D) \cong v_n(\pi) < v_n(p)$
- p_T > 8 GeV/c: path-length dependence of in-medium energy loss
  - ➡ $v_n(J/\psi) \cong v_n(D) \cong v_n(\pi) \cong v_n(p)$

Anisotropic flow of heavy-flavour hadrons



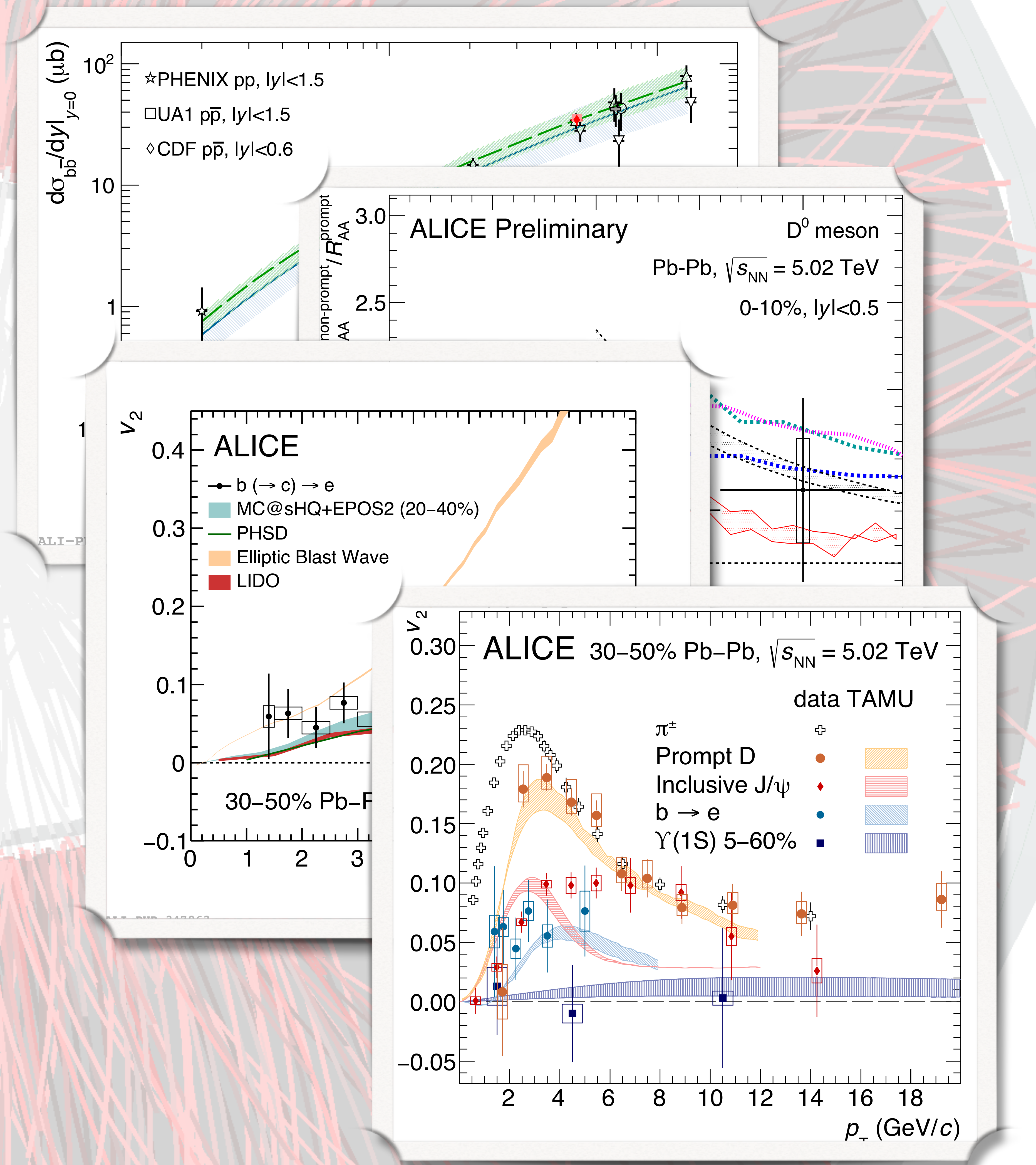
Pb–Pb $\sqrt{s_{NN}}$ = 5.02 TeV

- Positive v_2 of leptons from beauty-hadrons decays → collective motion of the system
- Υ(1S) v_2 compatible with zero and lower than J/ψ
- Simultaneous description of v_n (and R_{AA}) of different hadrons
  - ➡ challenge for theoretical models
- Precise measurements of different hadron species crucial for setting constraints to models
  - ➡ constrain diffusion coefficient D_s (∝ relaxation time)

    → $1.5 < 2\pi D_s T_c < 7$

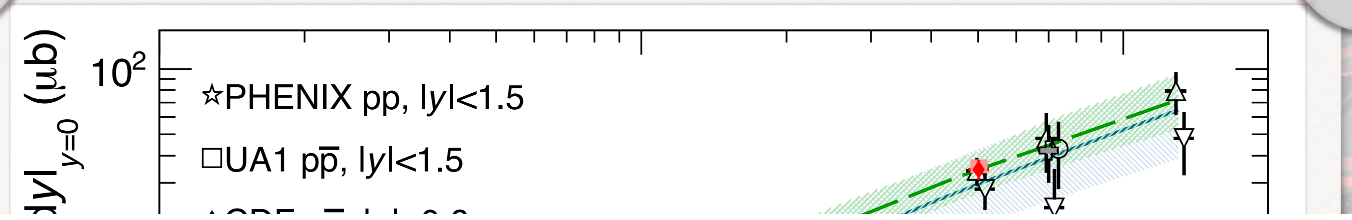
📖 ALICE $\pi^\pm$: JHEP 1809 (2018) 006
📖 ALICE J/ψ: JHEP 10 (2020) 141
📖 ALICE Prompt D: PLB 813 (2021) 136054
📖 ALICE b→e: PRL 126 (2021) 162001
📖 ALICE Υ(1S): PRL 123 (2019) 192301

Conclusions & outlook



- ALICE measured open charm and beauty hadrons production in different colliding systems
  - Measurements in pp collisions
    - ➡ production cross sections described by pQCD calculations
    - ➡ precise study of charm and beauty hadronisation
  - Production in heavy-ion collisions
    - ➡ better precision and extended p_T range
    - ➡ insight into quark-mass dependence of the in-medium parton energy loss
- Anisotropic flow
  - ➡ insight into heavy-flavour hadronisation via fragmentation and coalescence

Conclusions & outlook



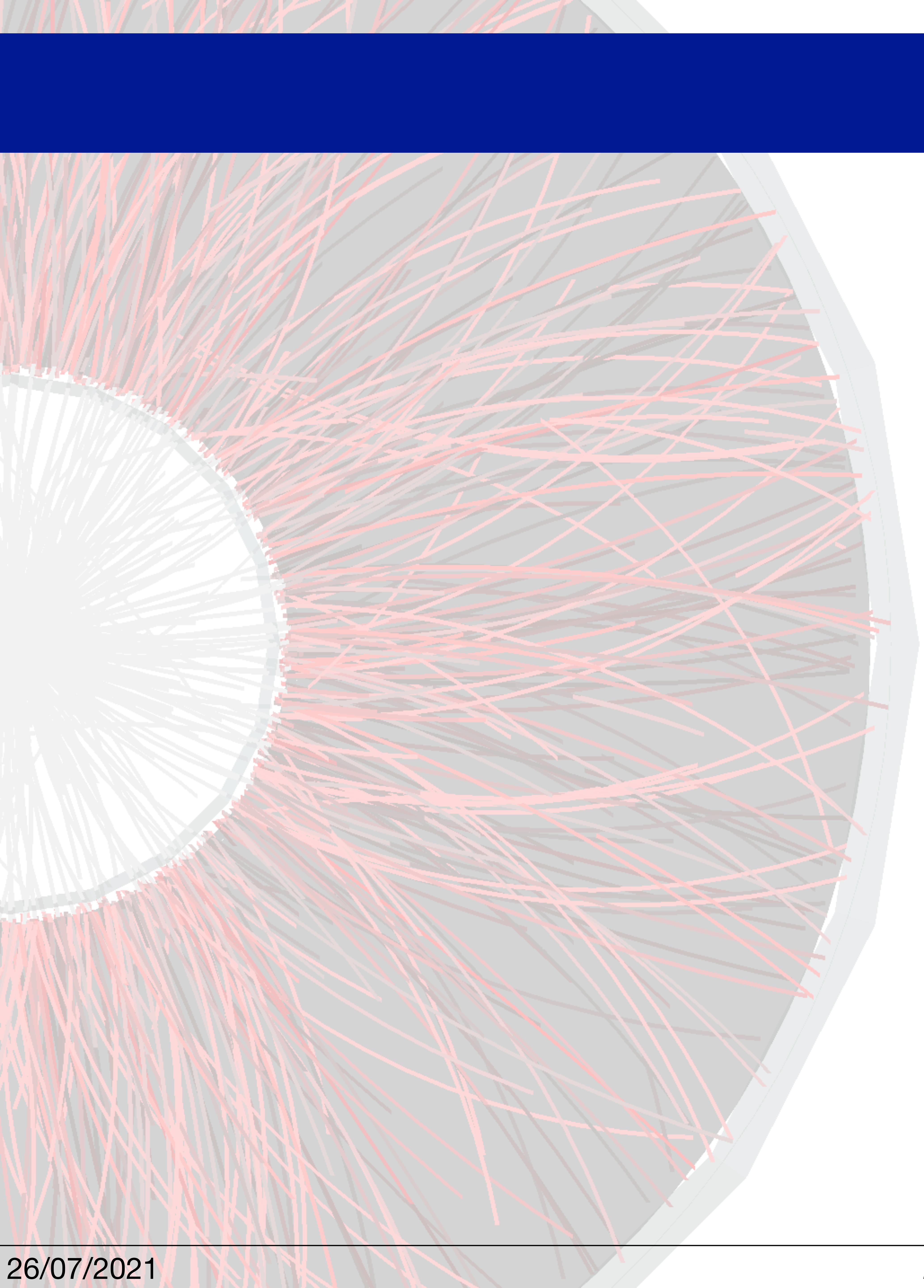
- ALICE measured open charm and beauty hadrons production in different colliding systems

More on **heavy-flavour production…**

- Vit Kucera - 26th July, h 15:30*
  "Jet substructure measurements in proton-proton collisions with ALICE"
- Luigi Dello Stritto - 27th July, h 10:15*
  "Charm cross section and fragmentation fractions in pp collisions with ALICE"
- Shingo Sakai - 27th July, h 10:30*
  "Measurement of electroweak-boson production in pp, p–Pb and Pb–Pb collisions with ALICE at the LHC"

*CEST timezone

➡ insight into heavy-flavour hadronisation via fragmentation and coalescence



Thank you for your attention!

for discussion and questions contact: strogolo@cern.ch

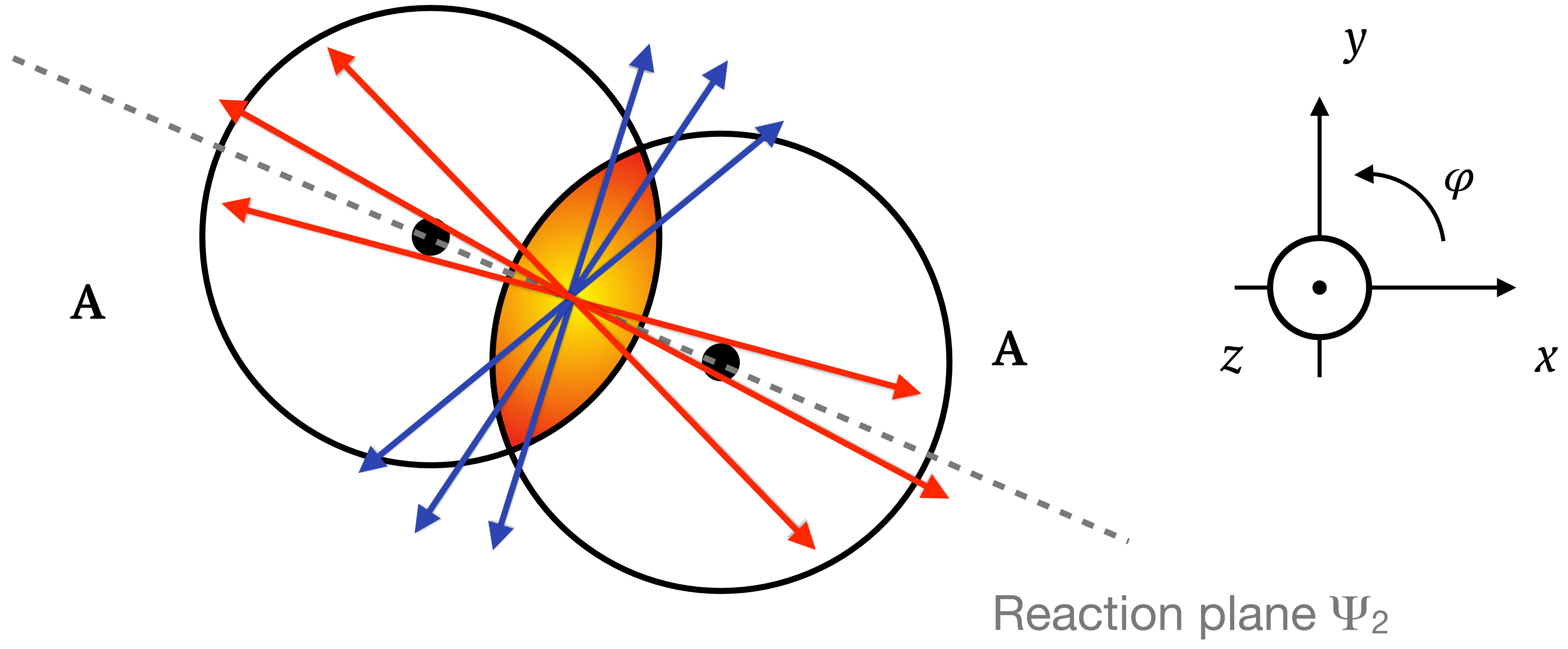
Additional material

Elliptic and triangular flow

$$E\frac{d^3N}{dp_T} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left\{1 + \sum_{i=1}^{\infty} v_n \cos[n(\varphi - \Psi_n)]\right\}$$

$$v_2 = \langle\cos[2(\varphi - \Psi_2)]\rangle$$

second harmonic coefficient
elliptic flow



- Elliptic flow (v_2): asymmetry between the in-plane and out-of-plane directions
  - ➡ low p_T: participation in collective motion and thermalization of heavy quarks
  - ➡ high p_T: path-length dependence of energy loss

Elliptic and triangular flow

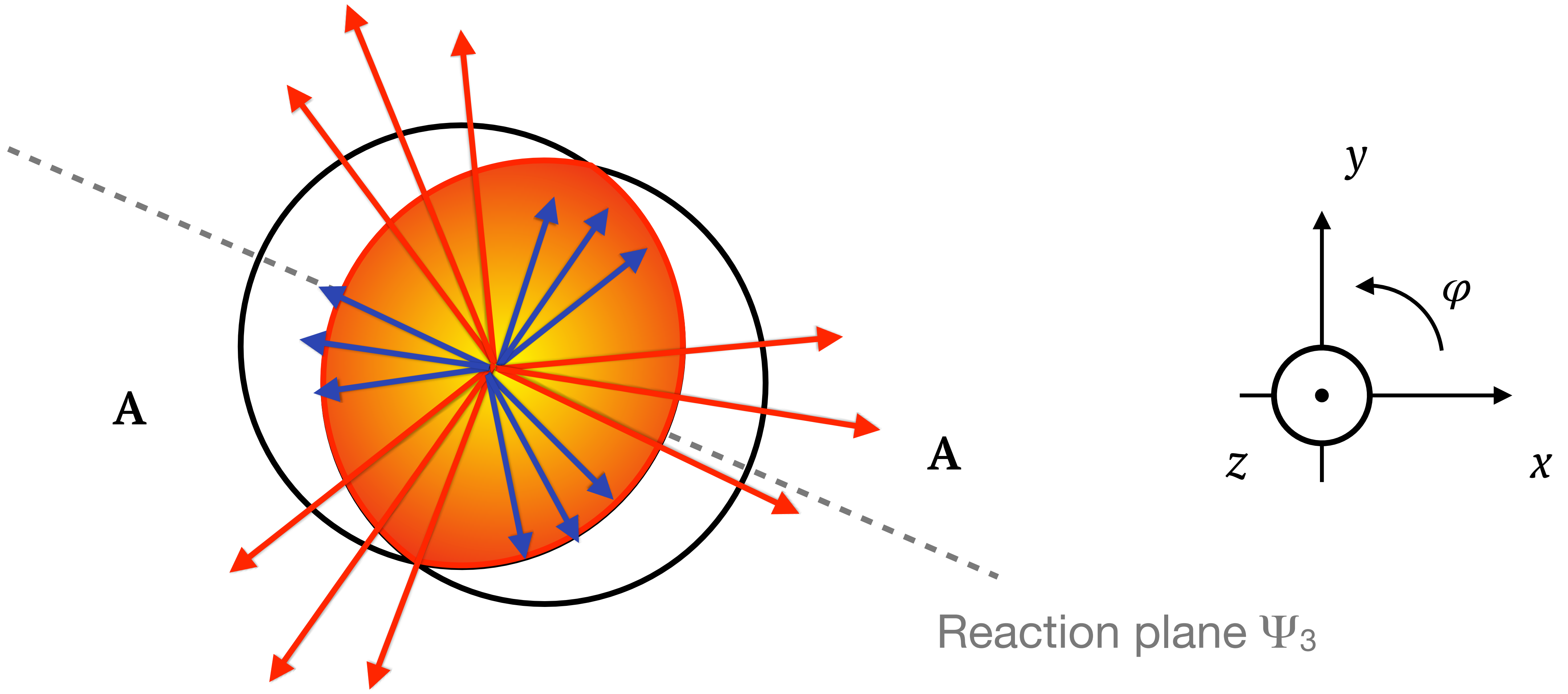
$$E\frac{d^3N}{dp_T} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left\{1 + \sum_{i=1}^{\infty} v_n \cos[n(\varphi - \Psi_n)]\right\}$$

$$v_2 = \langle\cos[2(\varphi - \Psi_2)]\rangle$$

second harmonic coefficient
elliptic flow

$$v_3 = \langle\cos[3(\varphi - \Psi_3)]\rangle$$

third harmonic coefficient
triangular flow



- Elliptic flow (v_2): asymmetry between the in-plane and out-of-plane directions
  - ➡ low p_T: participation in collective motion and thermalization of heavy quarks
  - ➡ high p_T: path-length dependence of energy loss
- Triangular flow (v_3): event-by-event fluctuations in the initial distributions of nucleons and gluons in the overlap region
  - ➡ sensitive to the ratio of the shear viscosity to the entropy density, η/s

Elliptic and triangular flow

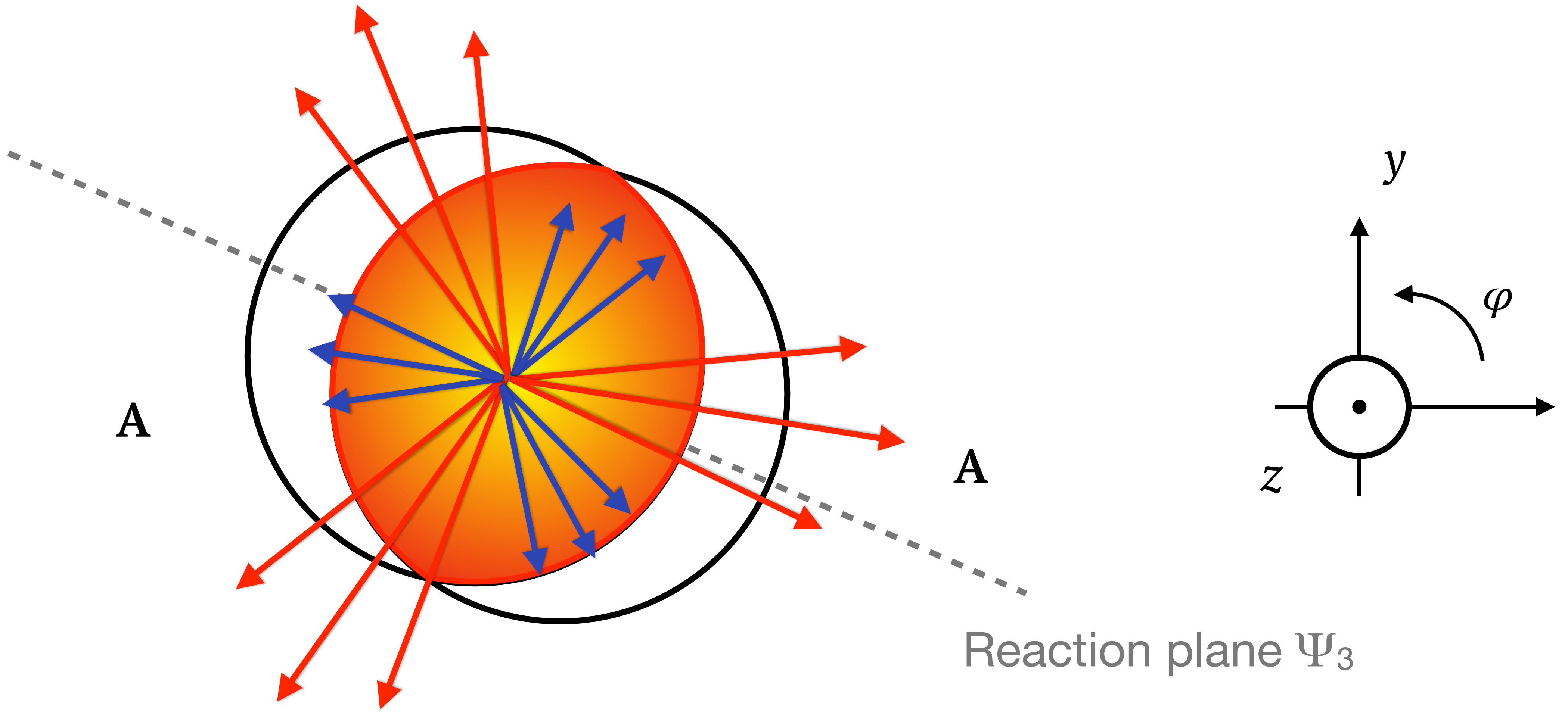
$$E\frac{d^3N}{dp_T} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left\{1 + \sum_{i=1}^{\infty} v_n \cos[n(\varphi - \Psi_n)]\right\}$$

$$v_2 = \langle\cos[2(\varphi - \Psi_2)]\rangle$$

second harmonic coeff.
elliptic flow

$$v_3 = \langle\cos[3(\varphi - \Psi_3)]\rangle$$

third harmonic coeff.
triangular flow



Event-shape engineering (ESE) [2]

technique that allows us to study various observables (e.g. v_n, yields,…) in classes of events corresponding to the same centrality, but different eccentricity

eccentricity ε

$$\langle q_n^2\rangle \simeq 1 + \langle(M-1)\rangle\langle(v_n^2 + \delta_n)\rangle$$

small ε → small q_n large ε → large q_n

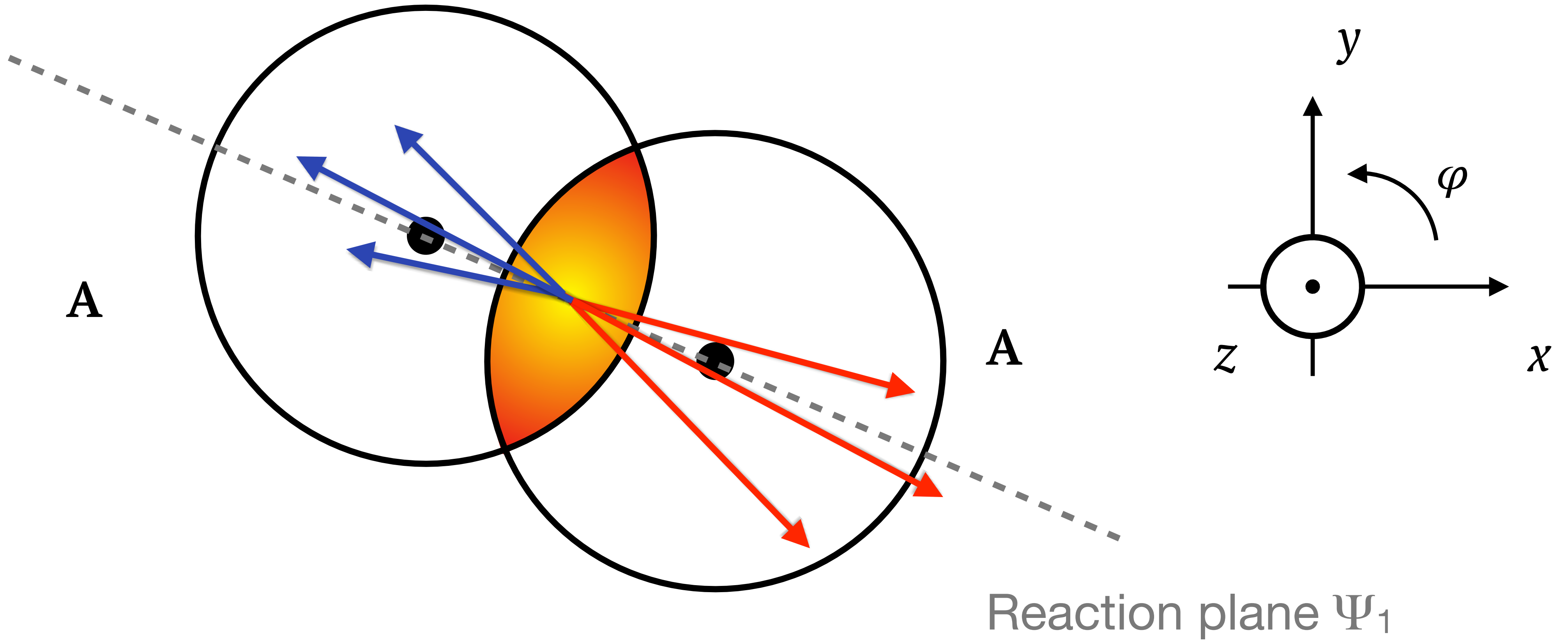
[2] J. Schukraft, A. Timmins, S. Voloshin, Phys. Lett. B 719, 394 (2013)

Charged-dependent directed flow

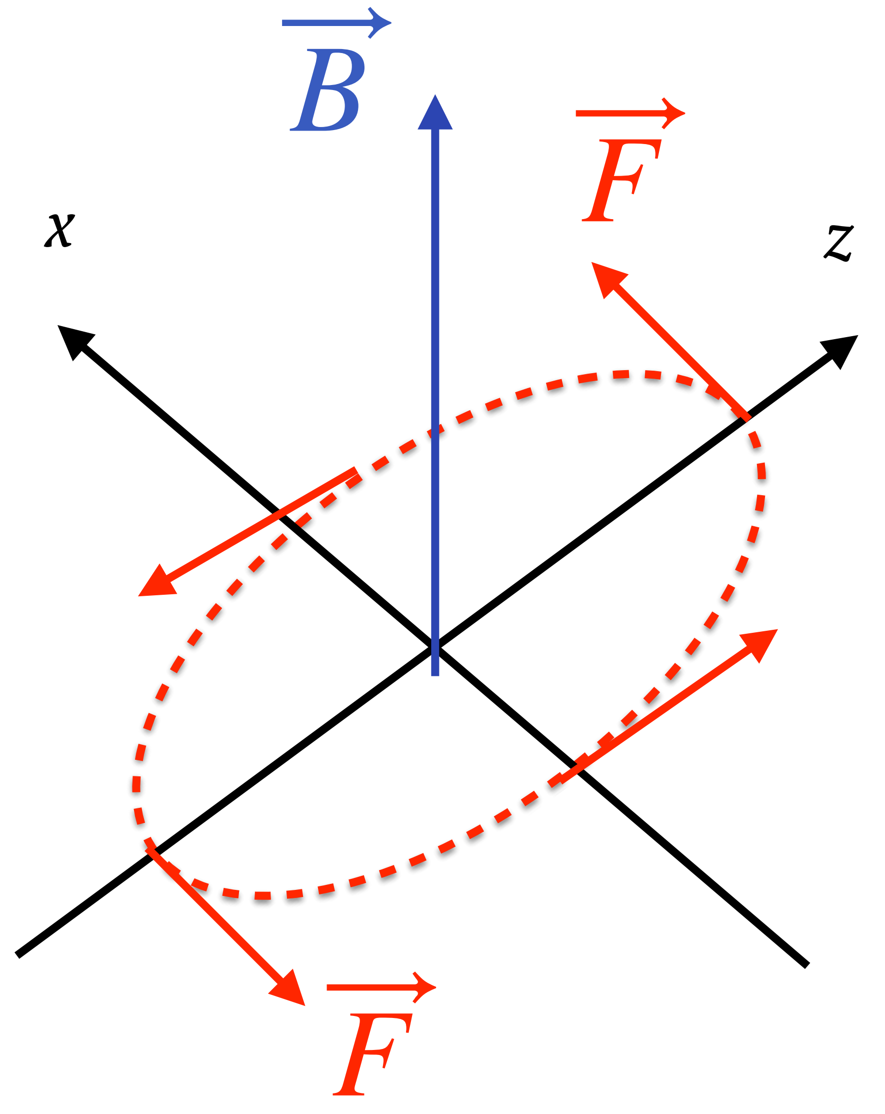
$$E\frac{d^3N}{dp_T} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left\{1 + \sum_{i=1}^{\infty} v_n \cos[n(\varphi - \Psi_n)]\right\}$$

$$v_1 = \langle\cos(\varphi - \Psi_1)\rangle$$

first harmonic coefficient
directed flow

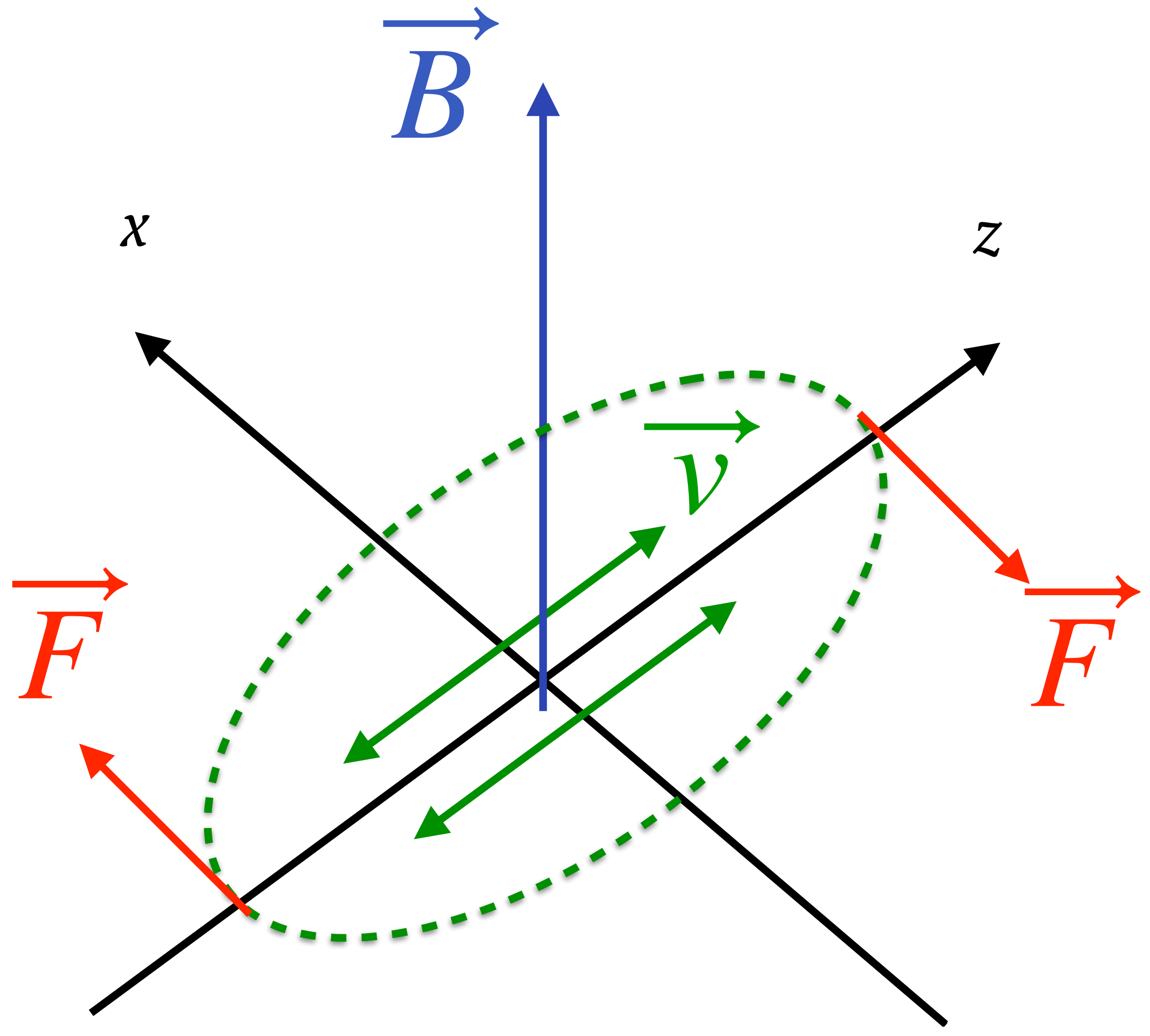


- Asymmetry between the forward and backward emission
- Charged-dependent v_1 → used to study the magnetic field created in heavy-ion collisions



➡ Faraday effect

Electric field induced by decreasing $\vec{B}$



➡ Hall effect

Lorentz force induced by moving charges

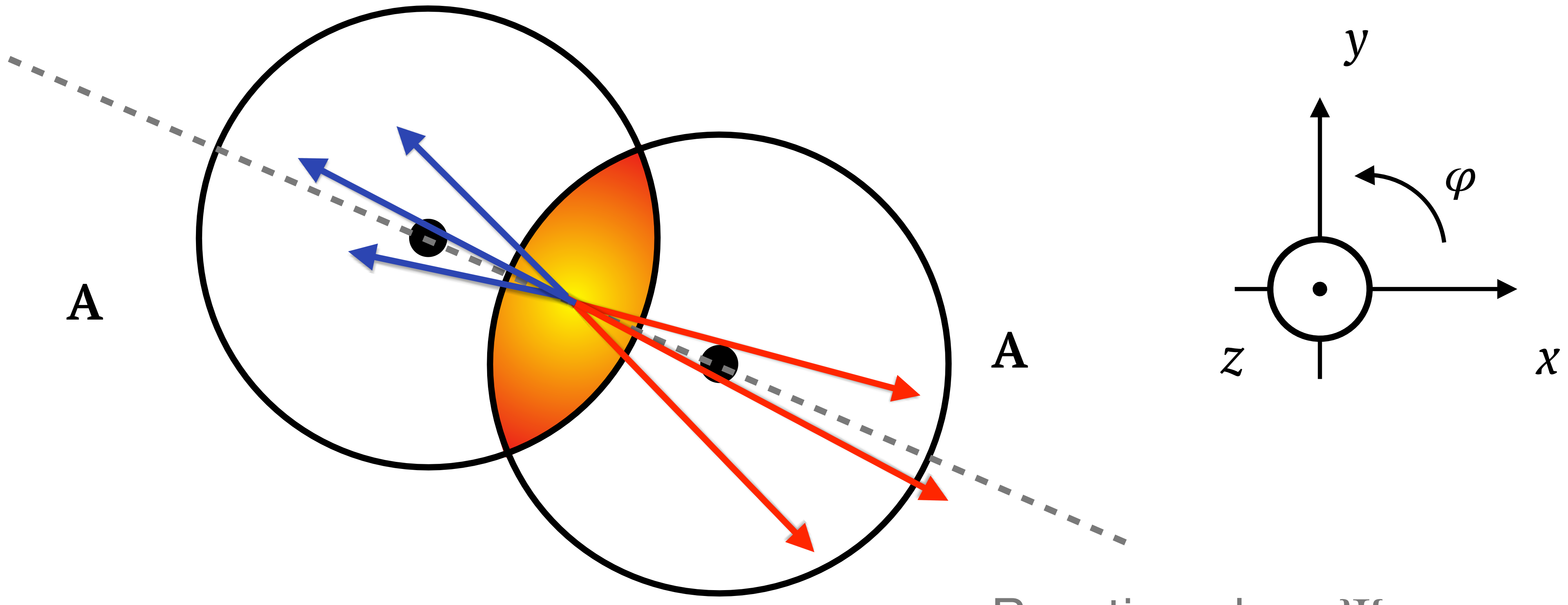
$$\vec{F} = q\vec{v} \times \vec{B}$$

Charged-dependent directed flow

$$E\frac{d^3N}{dp_T} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left\{1 + \sum_{i=1}^{\infty} v_n \cos[n(\varphi - \Psi_n)]\right\}$$

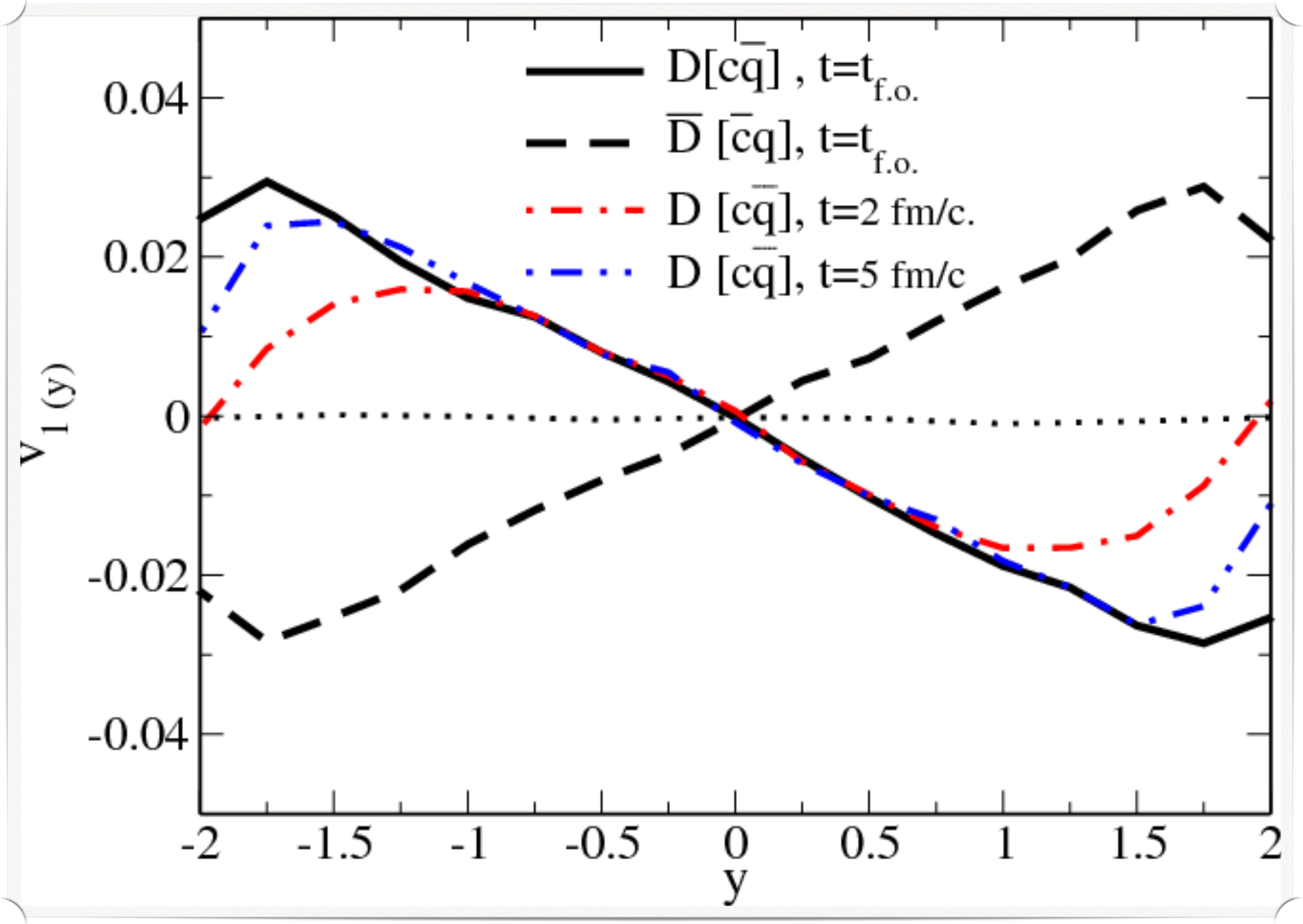
$$v_1 = \langle\cos(\varphi - \Psi_1)\rangle$$

first harmonic coefficient
directed flow



Reaction plane Ψ_1

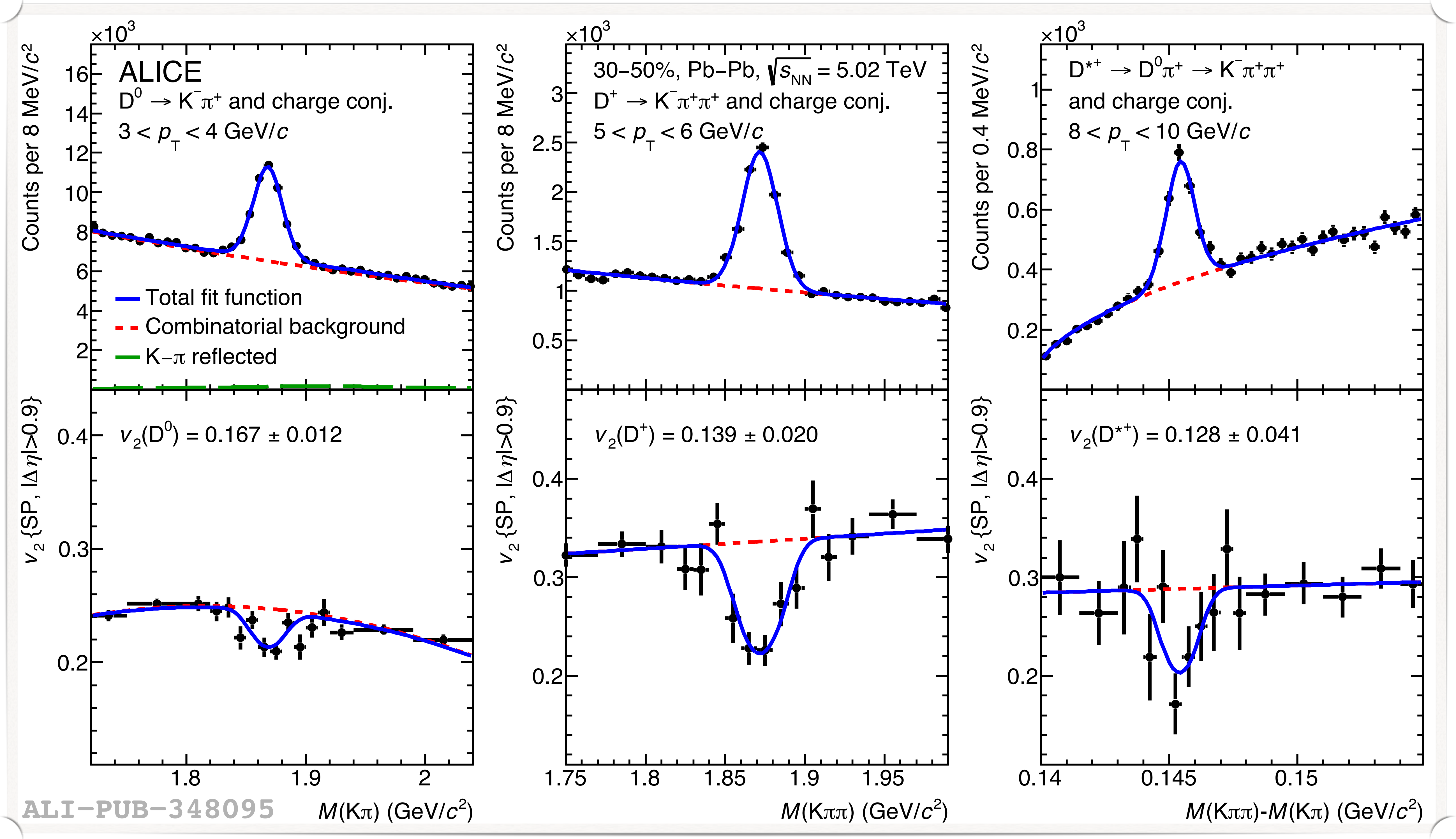
- **Charm quark** is an ideal probe:
  - ➡ **formation time** is comparable to the time scale when $\vec{B}$ reaches its maximum
  - ➡ **relaxation time** is similar to the QGP lifetime
  - ➡ expected **larger effect** compared to light hadrons



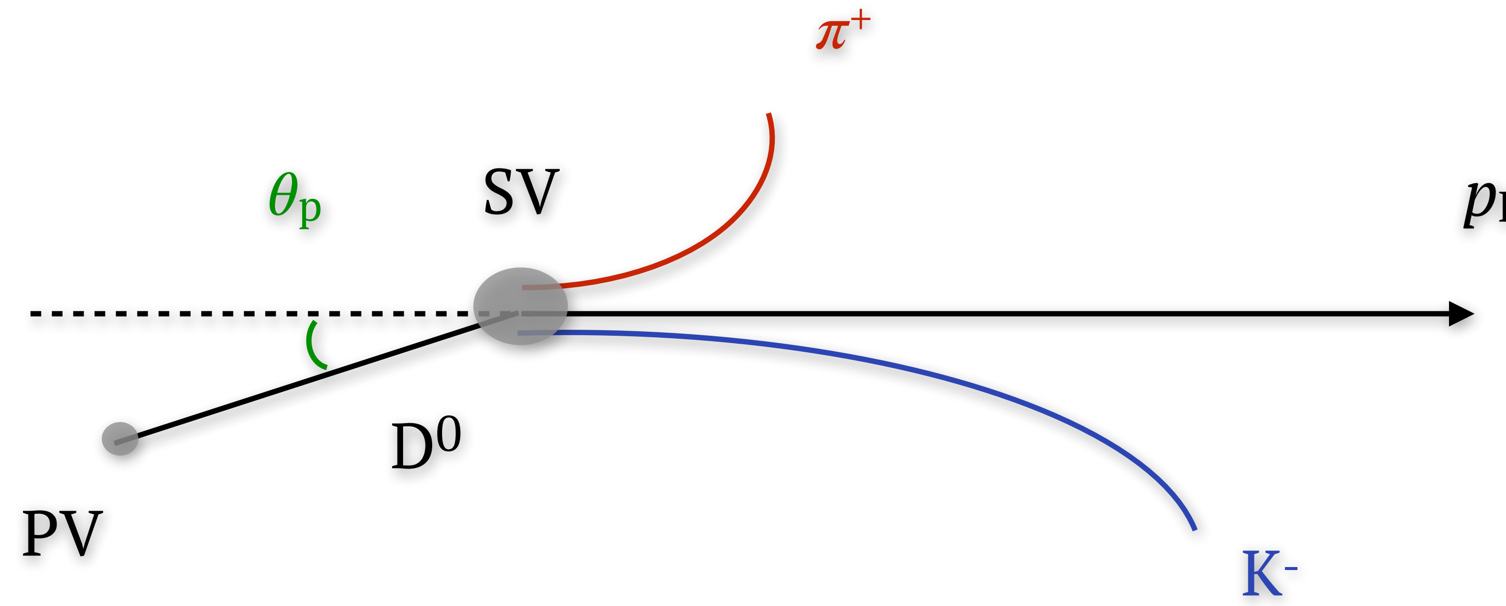
📖 K. Das et al, PLB 768 (2017) 260-264

D-meson reconstruction

Meson	Mass (GeV/c^2)	decay channel	$c\tau$ (μm)	BR (%)[3]
D^0 ($c\bar{u}$)	1.865	$K^-\pi^+$	123	3.95
D^+ ($c\bar{d}$)	1.870	$K^-\pi^+\pi^+$	312	9.38
D^{*+} ($c\bar{d}$)	2.010	D^0 ($\rightarrow K^-\pi^+$) π^+	strong decay	2.66
D_s^+ ($c\bar{s}$)	1.968	ϕ ($\rightarrow K^-K^+$) π^+	150	2.27



- Full reconstruction of hadronic decay channel
- Reduction of combinatorial background achieved applying:
  - geometrical selection of displaced decay-vertex topology
  - particle identification (PID)
- Signal from the invariant-mass analysis [4]
- Feed-down from b-hadrons subtracted with a FONLL-based method [5]



arXiv:2005.11131 [3] PDG, Phys. Rev. D 98, 030001 (2018), update 2019 [4] Borghini et al., PRC 70 (2004) 064905 [5] Cacciari et al., JHEP 1210 (2012) 137

D-meson v_n measurement

- Directed flow

$$v_1\{A,C\} = \frac{\langle \vec{u}_1 \cdot \vec{Q}_1^{A,C} \rangle}{\sqrt{\langle \vec{Q}_1^{A} \cdot \vec{Q}_1^{C} \rangle}}$$

➡ A (η > 8.8) and C (η < -8.8) denotes the ZDC sides

➡ rapidity-odd component separately for D^0 and $\overline{D}^0$

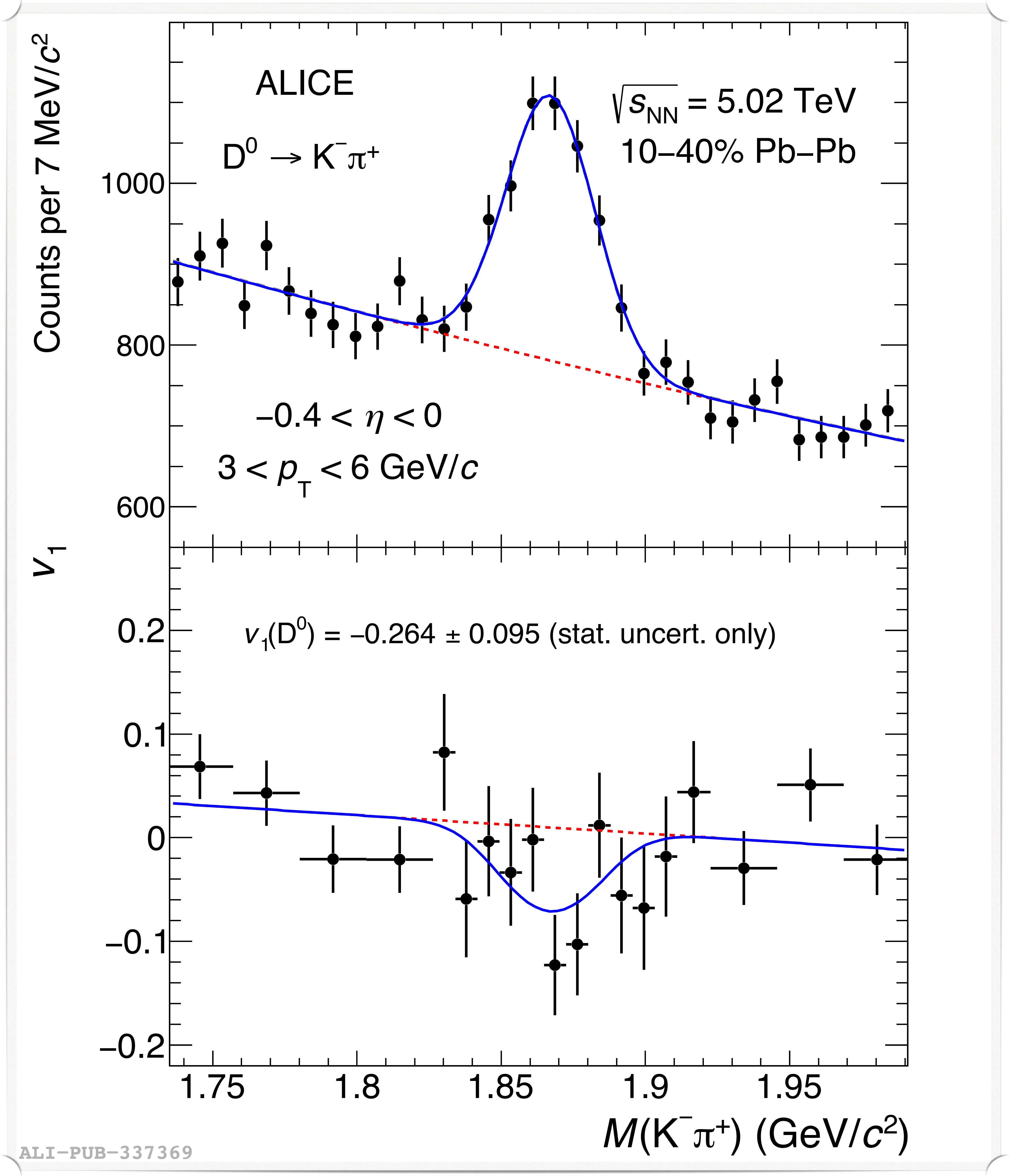
$$v_1^{odd} = \frac{1}{2}(v_1\{A\} - v_1\{C\})$$

- Elliptic and triangular flow

$$v_n\{SP\} = \langle \vec{u}_n \cdot \vec{Q}_n^{A} \rangle \Big/ \sqrt{\frac{\langle \vec{Q}_n^{A} \cdot \vec{Q}_n^{B} \rangle \langle \vec{Q}_n^{A} \cdot \vec{Q}_n^{C} \rangle}{\langle \vec{Q}_n^{B} \cdot \vec{Q}_n^{C} \rangle}}$$

➡ A, B and C refers to the V0C (–3.7 < η < –1.7), V0A (2.8 < η < 5.1) and TPC (|η| < 0.9) respectively

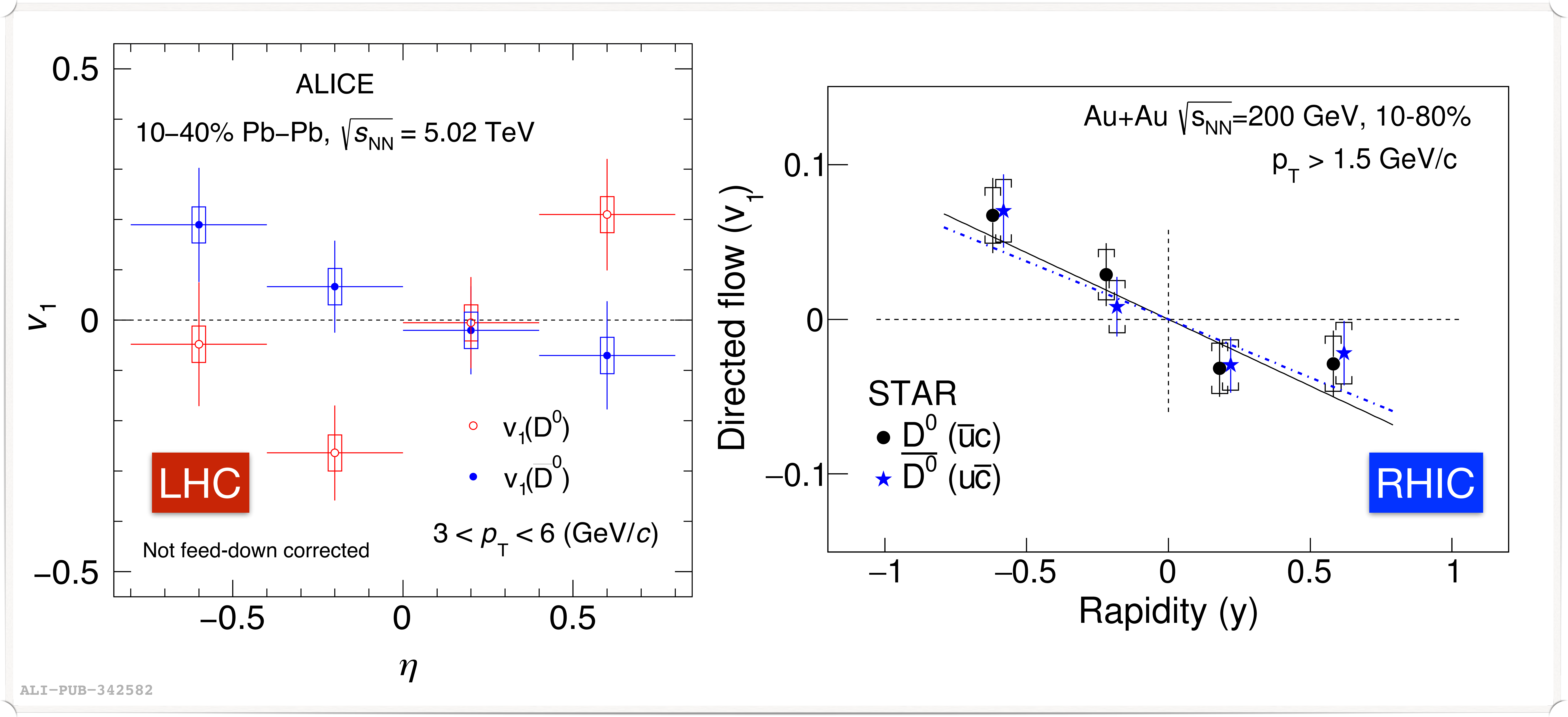
- **Flow coefficients** extracted with a simultaneous fit to the invariant-mass and v_n distributions [4]



[4] Borghini et al., PRC 70 (2004) 064905

📖 arXiv:1910.14406, Accepted by PRL

D^0 and $\overline{D^0}$ directed flow



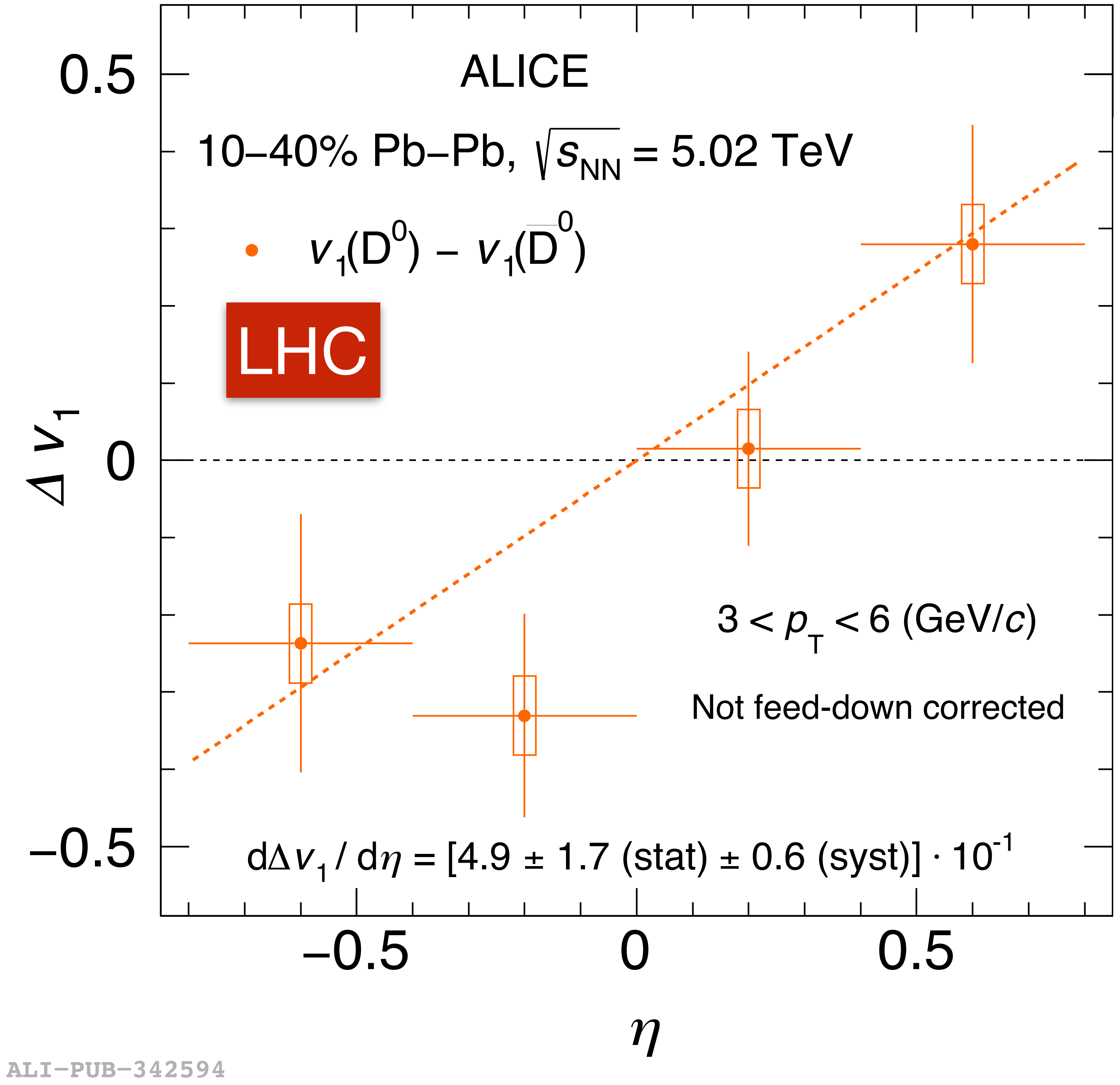
- At LHC: Possible hint of opposite trend of v_1^{odd} as a function of η for D^0 and $\overline{D^0}$
- At RHIC: Negative slopes for both D^0 and $\overline{D^0}$ as a function of rapidity

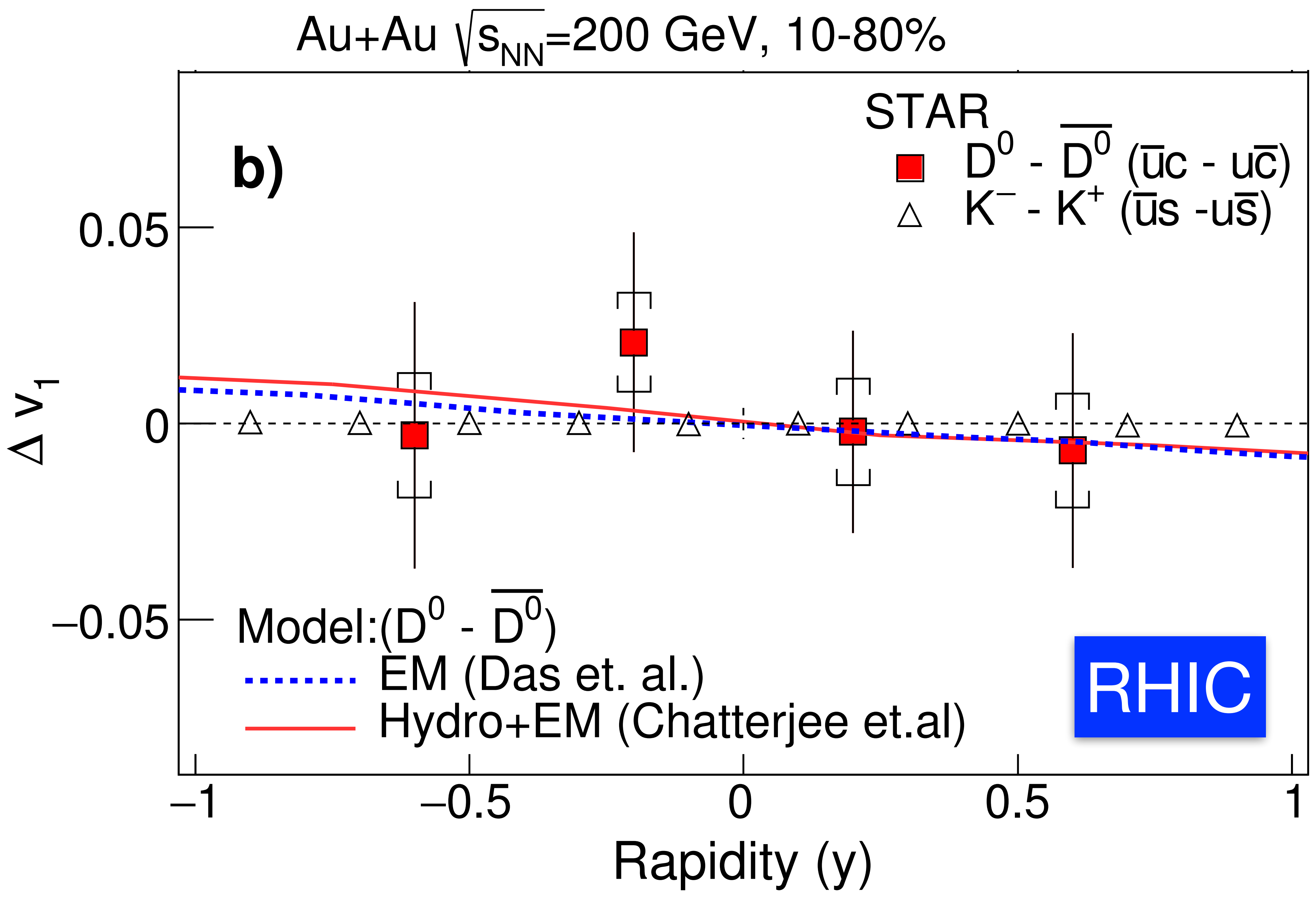
📖 ALICE, PRL 125 (2020) 022301

📖 STAR: PRL 123, 162301 (2019)

D^0 and $\overline{D}^0$ directed flow

📖 ALICE, PRL 125 (2020) 022301



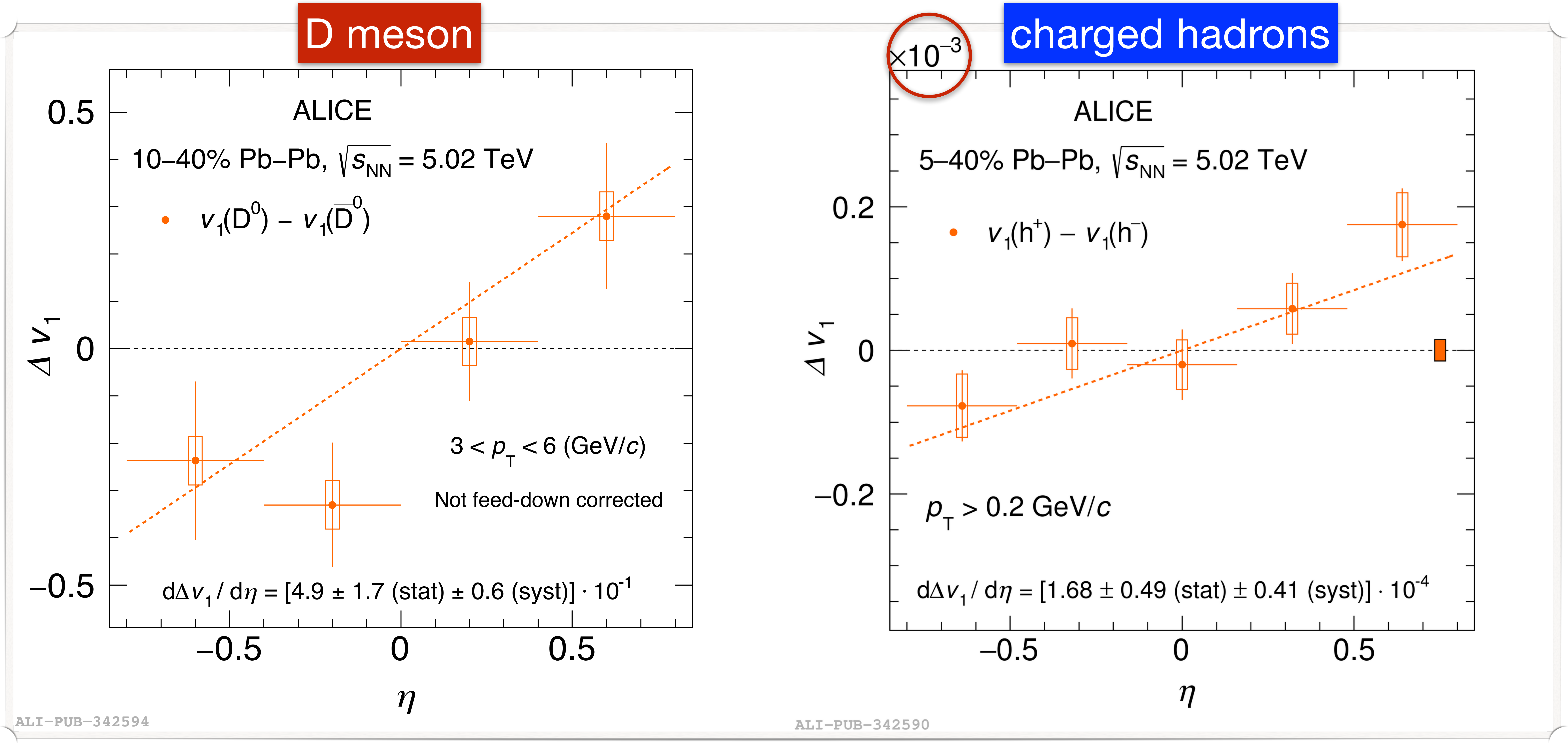


📖 STAR: PRL 123, 162301 (2019)

- At LHC: Δv_1^{odd} fitted with a linear function to quantify the effect → $\Delta v_1^{odd} = k \cdot \eta$
  ➡ Hint of positive slope with significance of 2.7σ
- At RHIC: Δv_1^{odd} compatible with zero → expected signal smaller than precision achieved

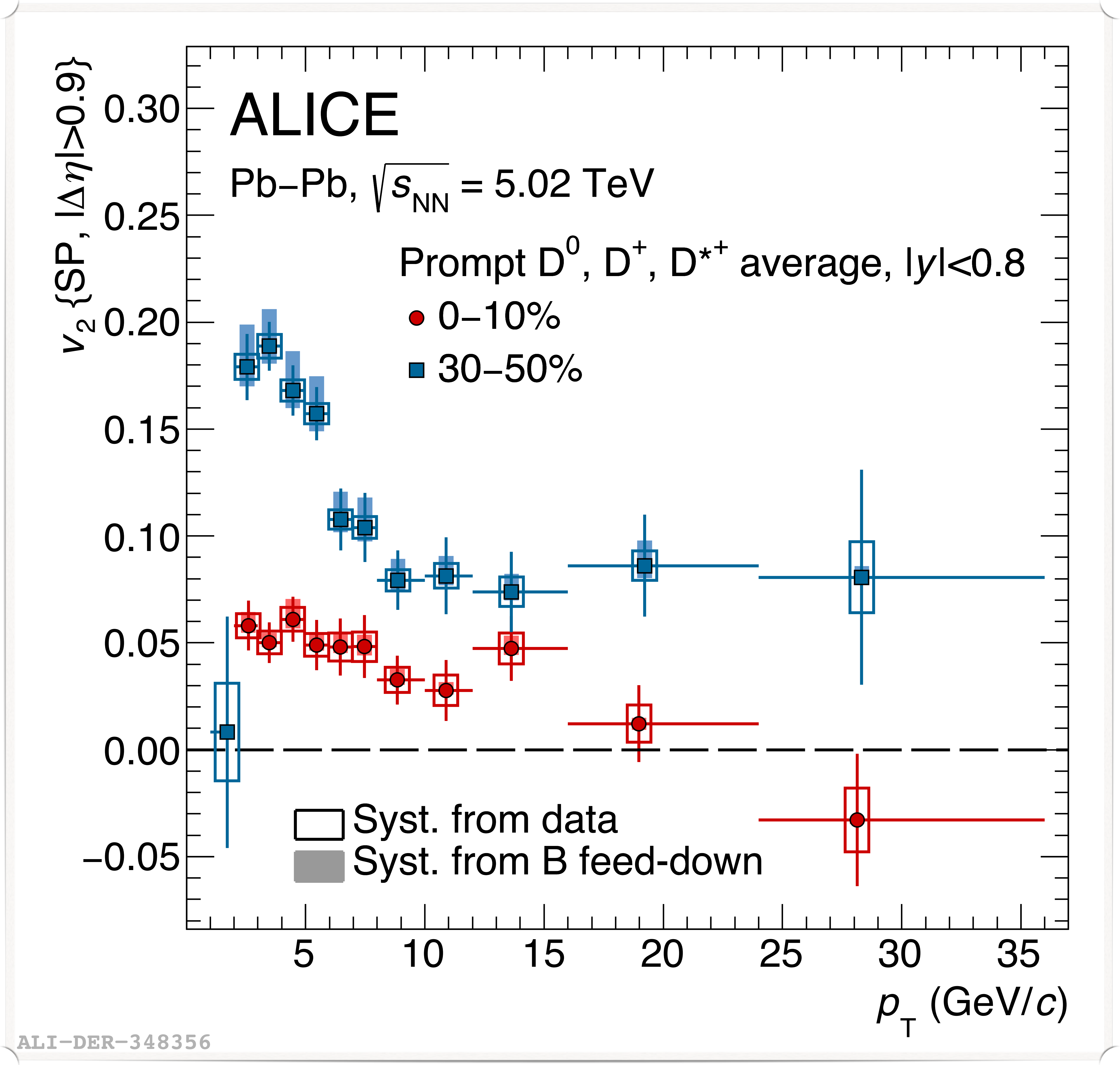
D^0 and $\overline{D}^0$ directed flow

📖 ALICE, PRL 125 (2020) 022301



- At LHC: Δv_1^{odd} fitted with a linear function to quantify the effect → $\Delta v_1^{odd} = k \cdot \eta$
  ➡ Hint of positive slope with significance of 2.7σ
- Similar trend observed for charged particles, but different magnitude

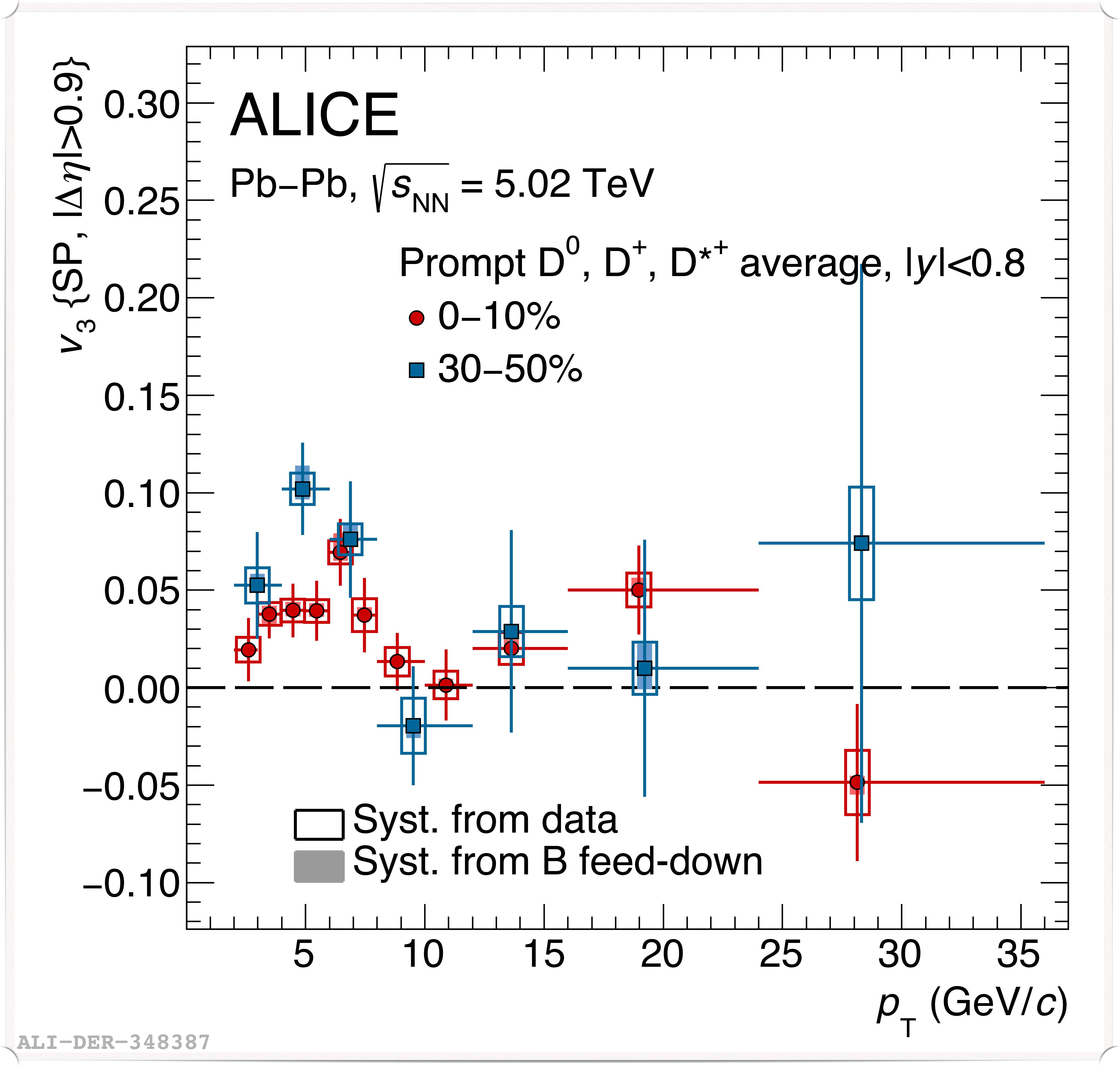
D-meson elliptic flow



- Non-strange D-meson v_2 in 0-10% and 30-50% centrality class
  - ➡ positive for p_T > 2 GeV/c
  - ➡ increases from central to semi-central
    → reflecting the increasing eccentricity of the interaction region

📖 ALICE, PLB 813 (2021) 136054

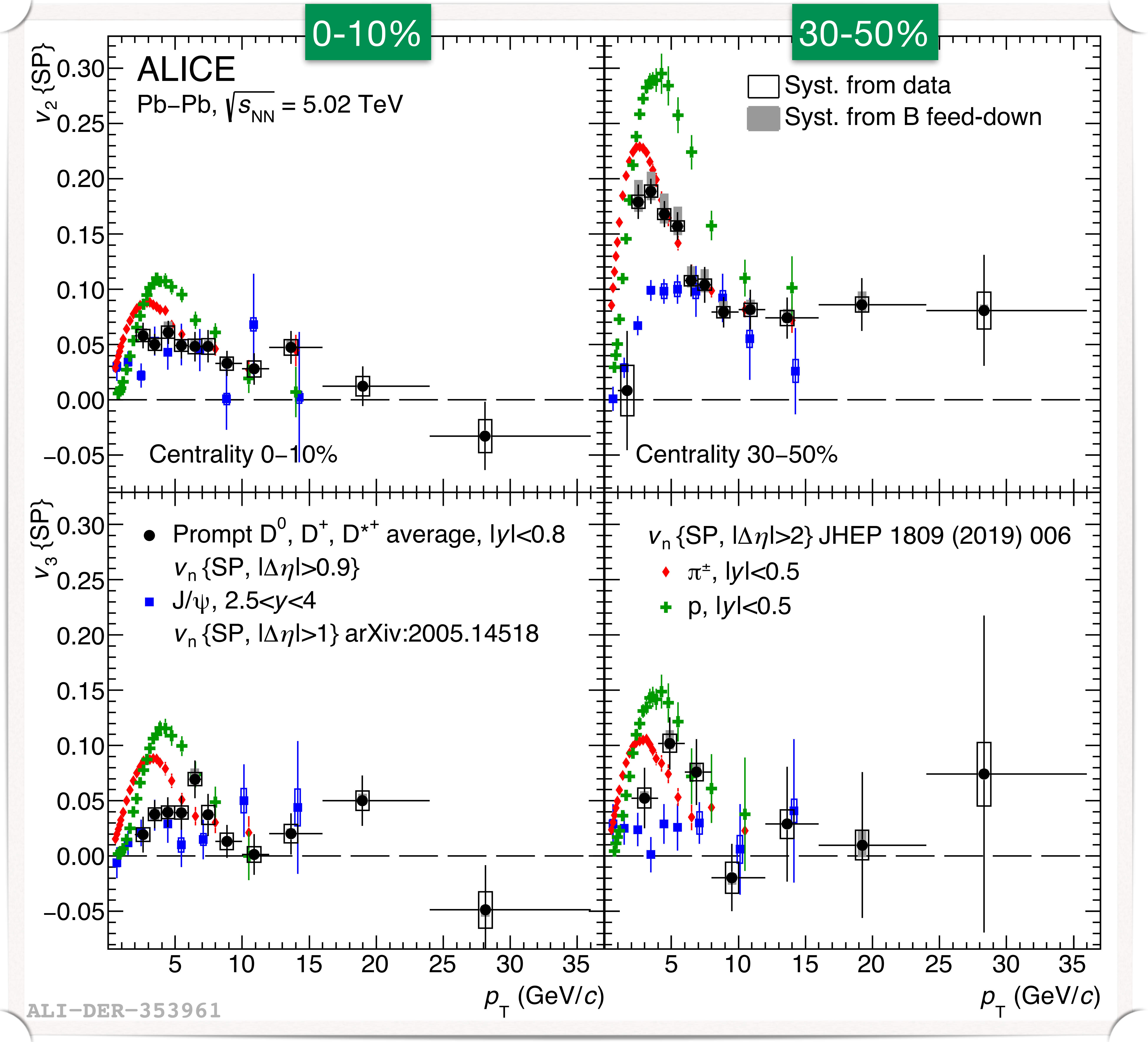
D-meson triangular flow



- Non-strange D-meson v_2 in 0-10% and 30-50% centrality class
  - ➡ positive for $p_T > 2$ GeV/c
  - ➡ increases from central to semi-central → reflecting the increasing eccentricity of the interaction region
- Non-strange D-meson v_3 in 0-10% and 30-50% centrality class
  - ➡ positive for $2 < p_T < 8$ GeV/c
  - ➡ compatible in the two centrality classes, as observed for light hadrons

📖 ALICE, PLB 813 (2021) 136054

D mesons vs. light hadrons



- Mass ordering for $p_T < 3$ GeV/c

$$v_n(J/\psi) < v_n(D) < v_n(p) < v_n(\pi)$$

- For $3 < p_T < 8$ GeV/c

$$v_n(D) \simeq v_n(\pi) < v_n(p)$$

➡ consistent with v_n constituent quark scaling

- $v_n(D) > v_n(J/\psi)$ for $3 < p_T < 6$ GeV/c

➡charm-quark coalescence with light quarks

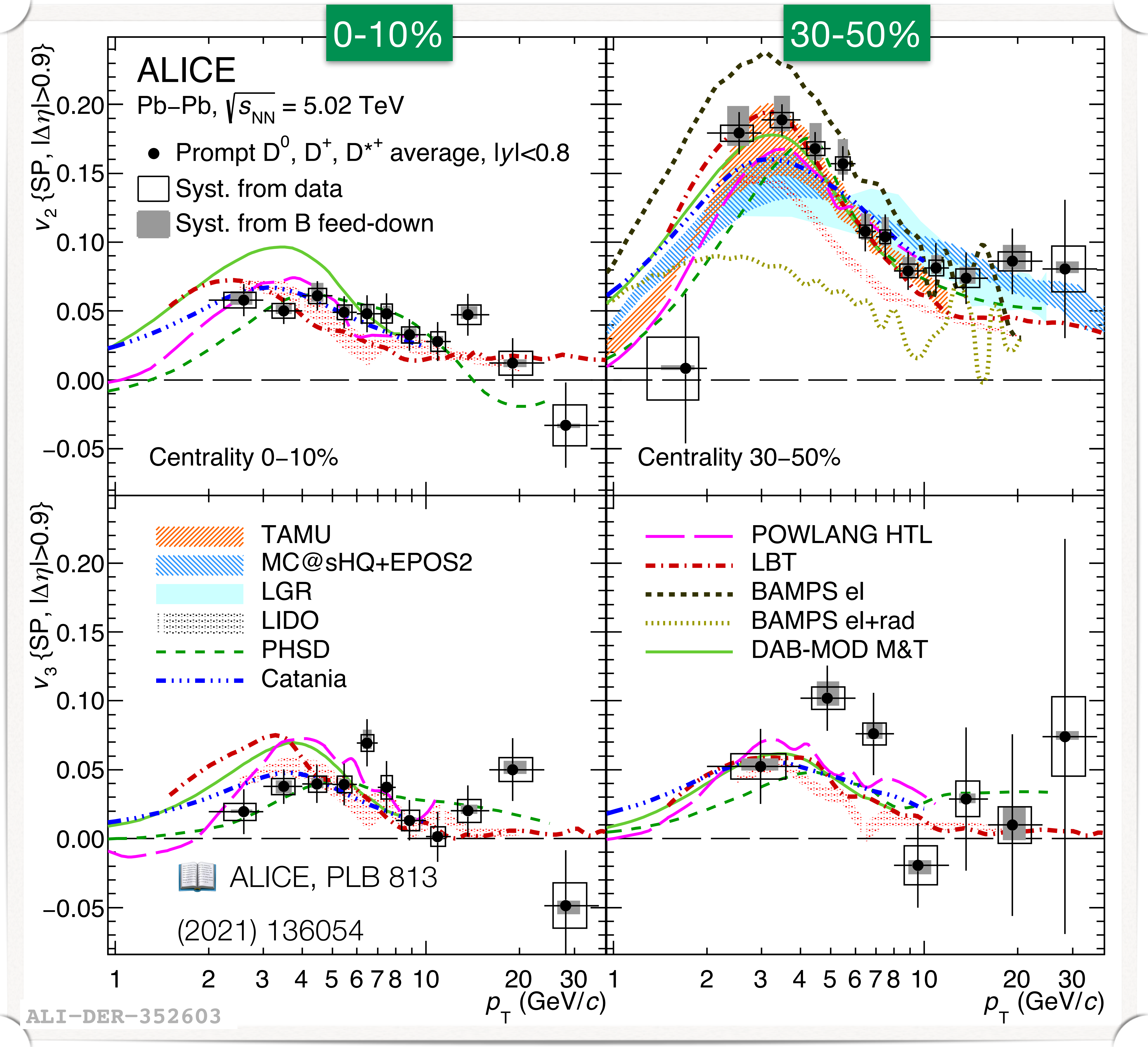
- For $p_T > 8$ GeV/c all v_n are similar

➡ consistent with path-length dependence of in-medium energy loss similar for quarks and gluons

📖 ALICE, PLB 813 (2021) 136054

📖 $\pi^{\pm}$,p: JHEP 1809 (2018) 006 📖 J/ψ: arXiv:2005.14518

Elliptic and triangular flow vs. models



- All models with hadronisation via **quark coalescence and fragmentation** fairly describe the measured v_n harmonics
- Constrain **charm spatial diffusion coefficient**

$$D_s = (T/m_Q)\tau_Q$$

➡ from models describing v_n with χ^2/ndf < 2

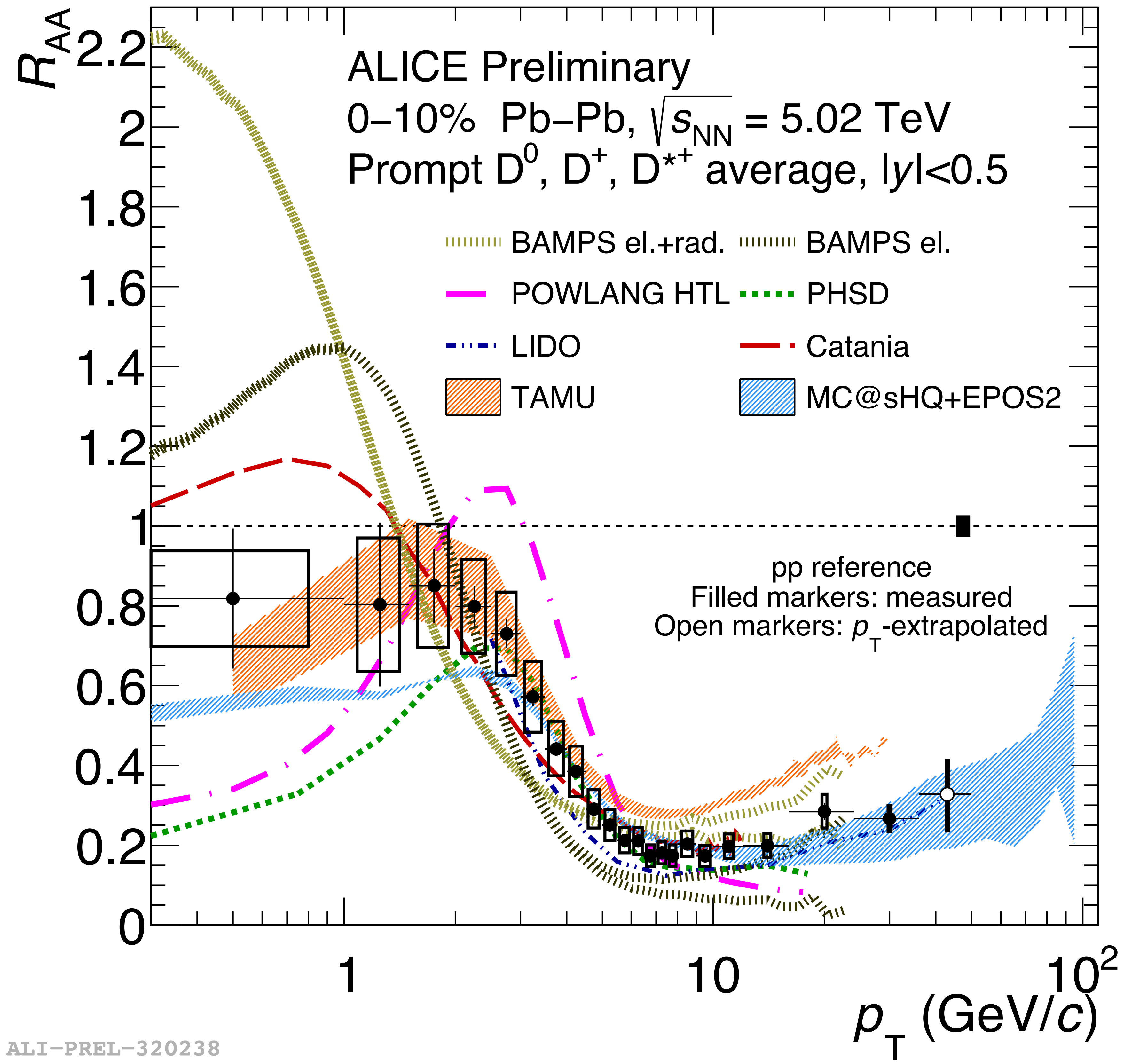
$$1.5 < 2\pi T_c D_s < 7$$

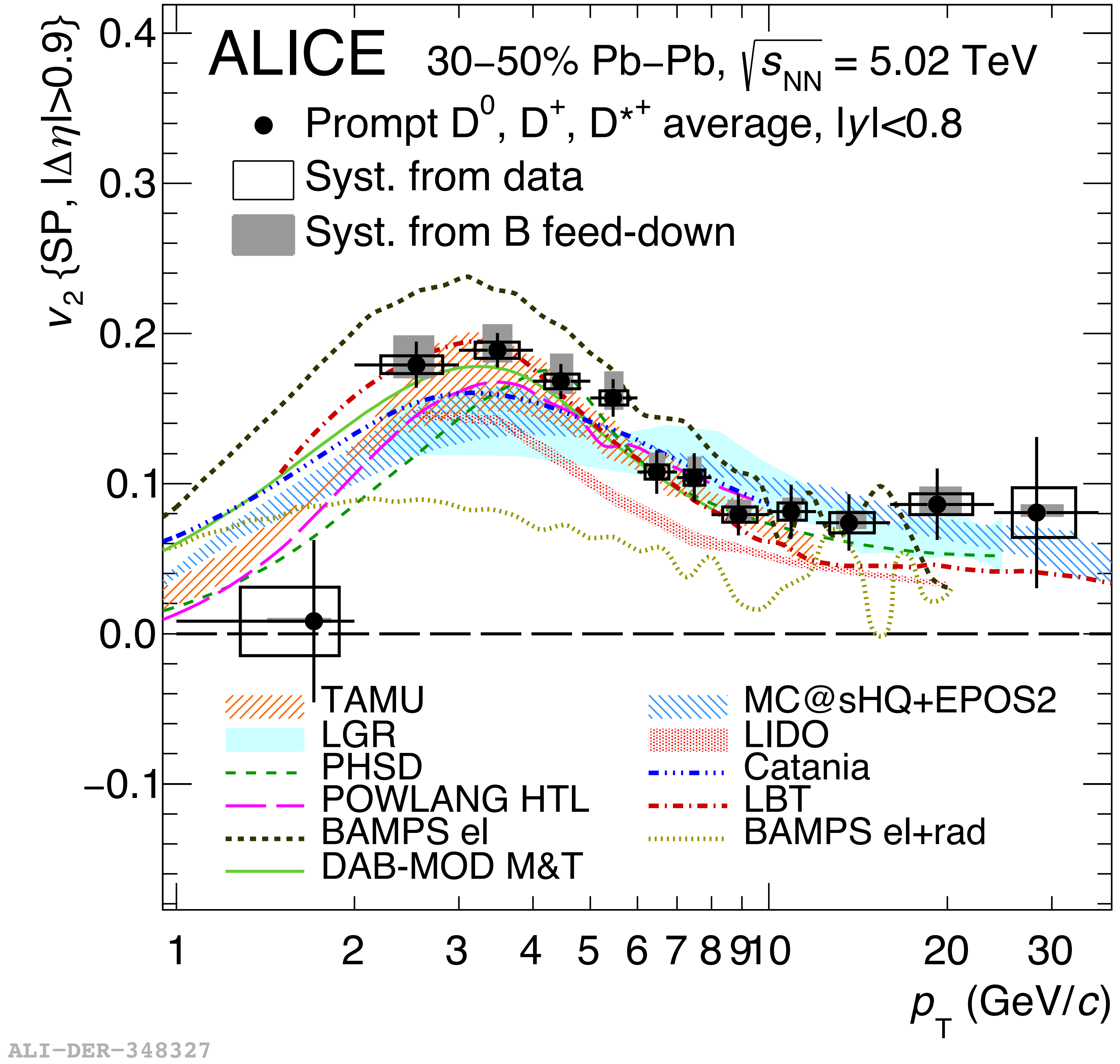
➡ leading to the charm thermalization time

$$\tau_{charm} = 3 - 14 \text{ fm}/c$$

TAMU: PRL 124, 042301 (2020)
MC@sHQ+EPOS: PRC 91, 014904 (2015)
BAMPS: JPG 42, 115106 (2015)
LIDO: PRC 98 064901 (2018)
PHSD: PRC 93, 034906 (2016)
LBT: PLB 777 (2018) 255-259
POWLANG: EPJC 75, 121 (2015)
LGR: arXiv:1912.08965
CATANIA: PRC 96, 044905 (2017)
DAB-MOD M&T: PRC 96 064903 (2017)

Simultaneous description of R_{AA} and v_2

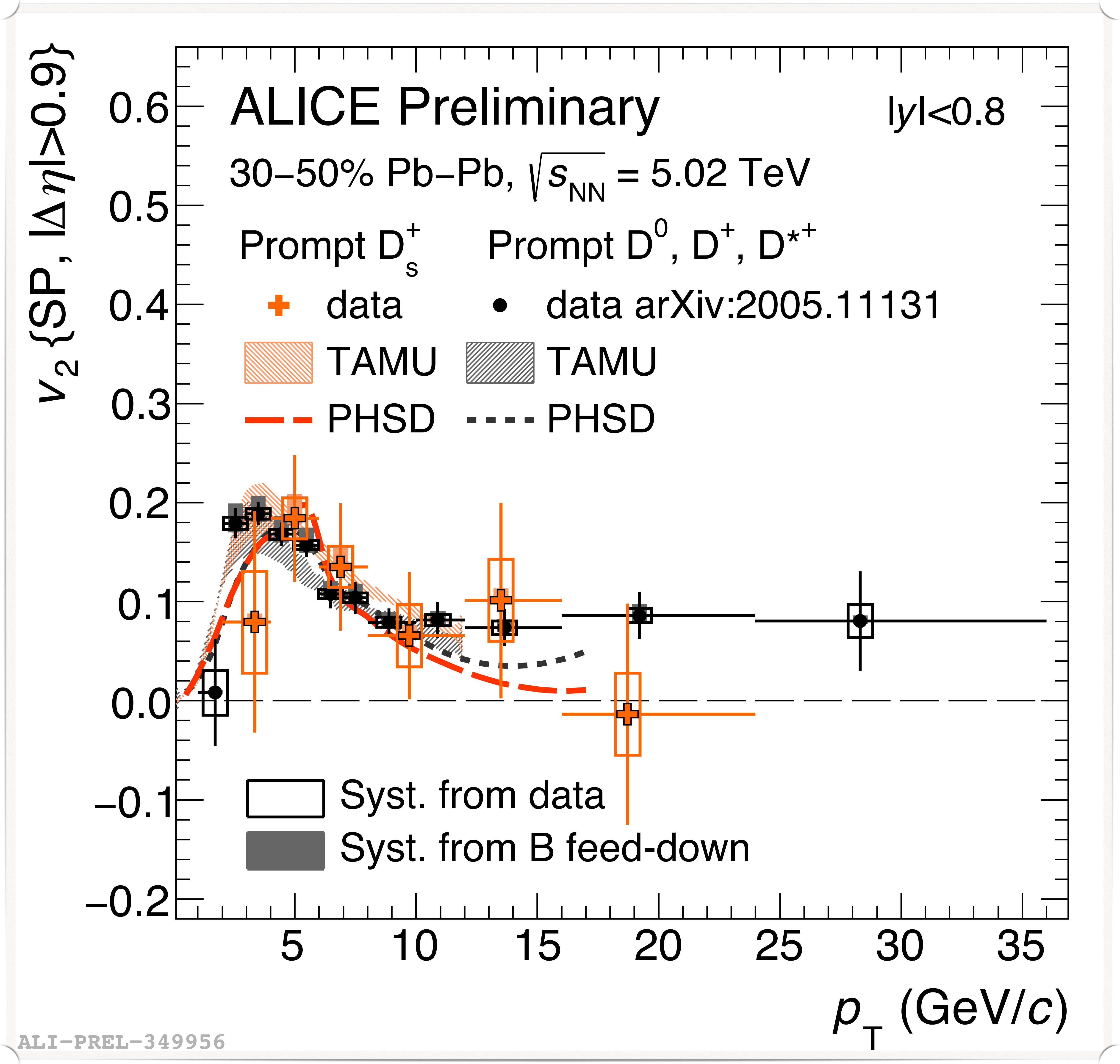




- TAMU: PRL 124, 042301 (2020)
- BAMPS: JPG 42, 115106 (2015)
- PHSD: PRC 93, 034906 (2016)
- POWLANG: EPJC 75, 121 (2015)
- CATANIA: PRC 96, 044905 (2017)
- MC@sHQ+EPOS: PRC 91, 014904 (2015)
- LIDO: PRC 98 064901 (2018)
- LBT: PLB 777 (2018) 255-259
- LGR: arXiv:1912.08965
- DAB-MOD M&T: PRC 96 064903 (2017)

- Data precision constrains the description of charm-interaction and diffusion in the medium at low p_T
- Interplay of nuclear shadowing, collisional and radiative energy loss, coalescence, flows required to describe the data

Charming strangeness



- D_s^+ v_2 measured with the same technique as for non-strange D mesons
  ➡ improved precision and extended p_T range towards high momenta
- D_s^+ v_2 in 30-50% compatible within uncertainty with non-strange D-meson v_2
- Charm-quark transport model can fairly describe both strange and non-strange v_2

📖 D^0, D^+, D^{*+} ALICE, PLB 813 (2021) 136054

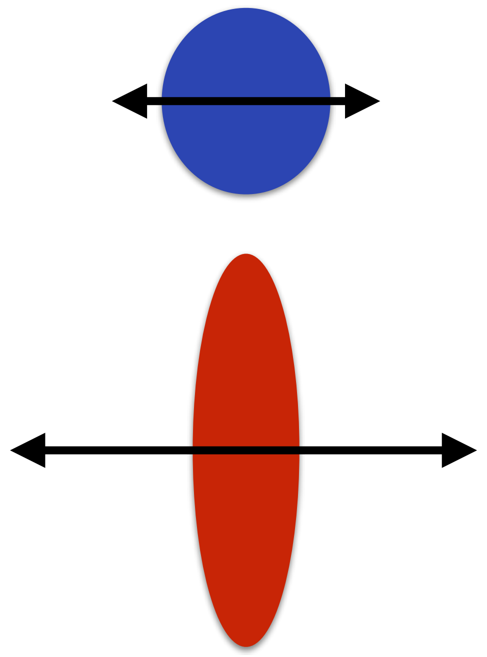
📖 TAMU: PRL 124, 042301 (2020)   📖 PHSD: PRC 93, 034906 (2016)

Event-shape engineering

- **Classification** of events at a certain centrality according to the **magnitude of the n^{th}-harmonic reduced flow vector**:

$$q_2 = |\vec{Q}_2|/\sqrt{M}$$

$$\vec{Q}_2 = \sum_{j=1}^{M} e^{i2\varphi_j}$$

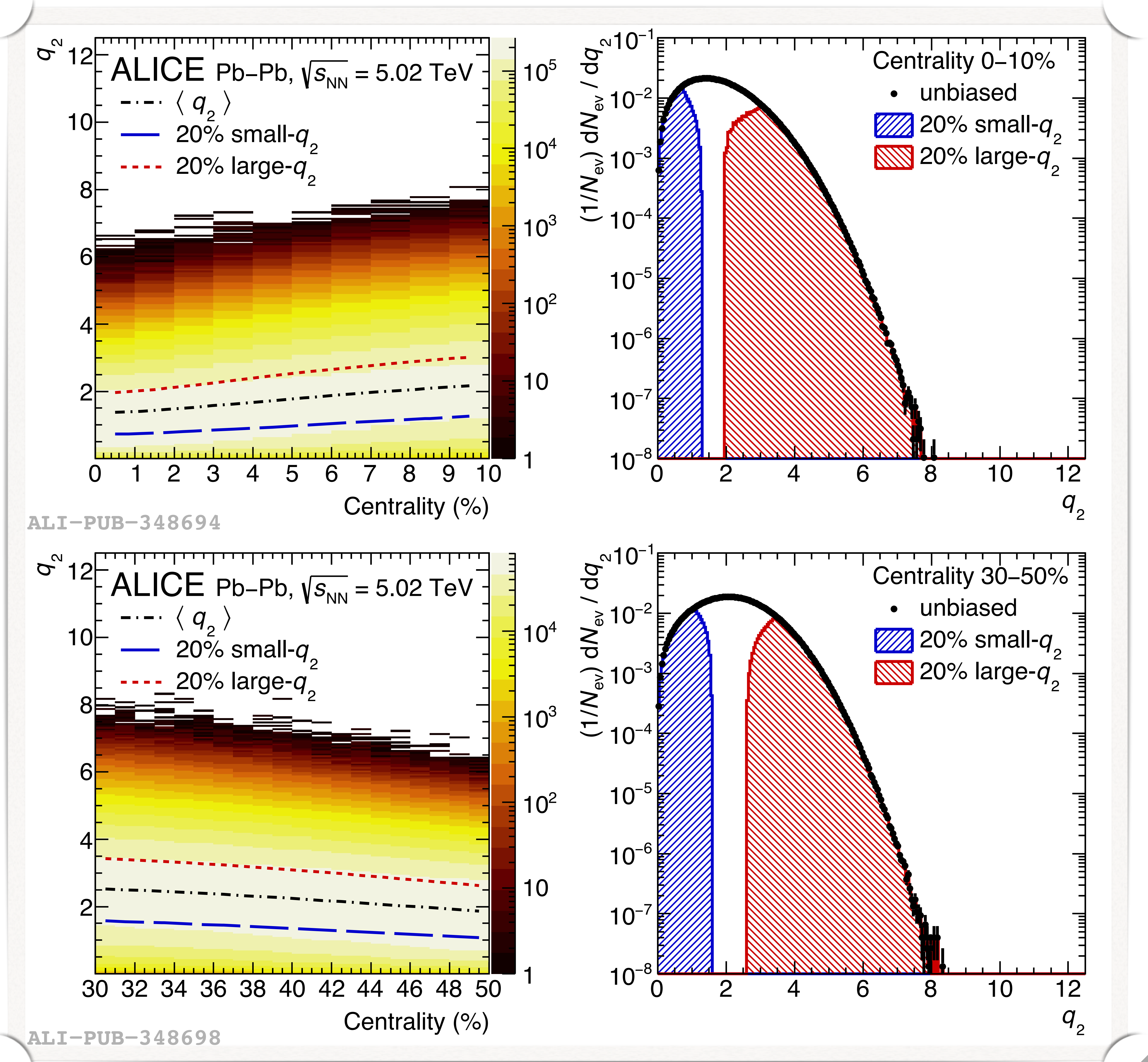


20% smallest q_2^{TPC}

$\langle v_2 \rangle_{small-q_2} < \langle v_2 \rangle_{unb}$

20% largest q_2^{TPC}

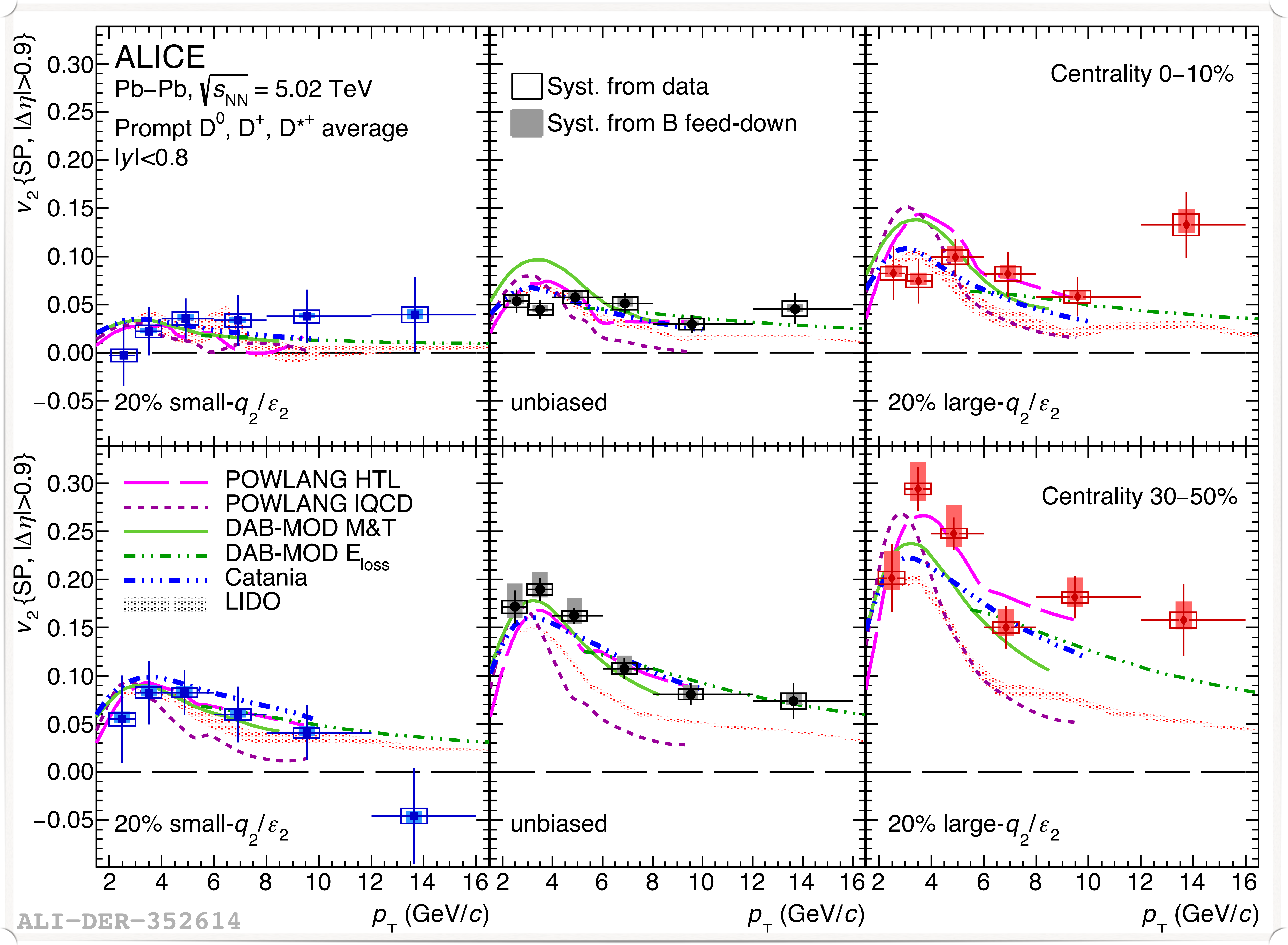
$\langle v_2 \rangle_{large-q_2} > \langle v_2 \rangle_{unb}$



ALICE, PLB 813 (2021) 136054 ALICE-PUBLIC-2020-003

- **Elliptic flow** for different q_2 samples:
  - ➡ **correlation** between v_2 of **D mesons** and **soft hadrons**
  - ➡ event-by-event **fluctuations** in the **initial state**

ESE-selected elliptic flow

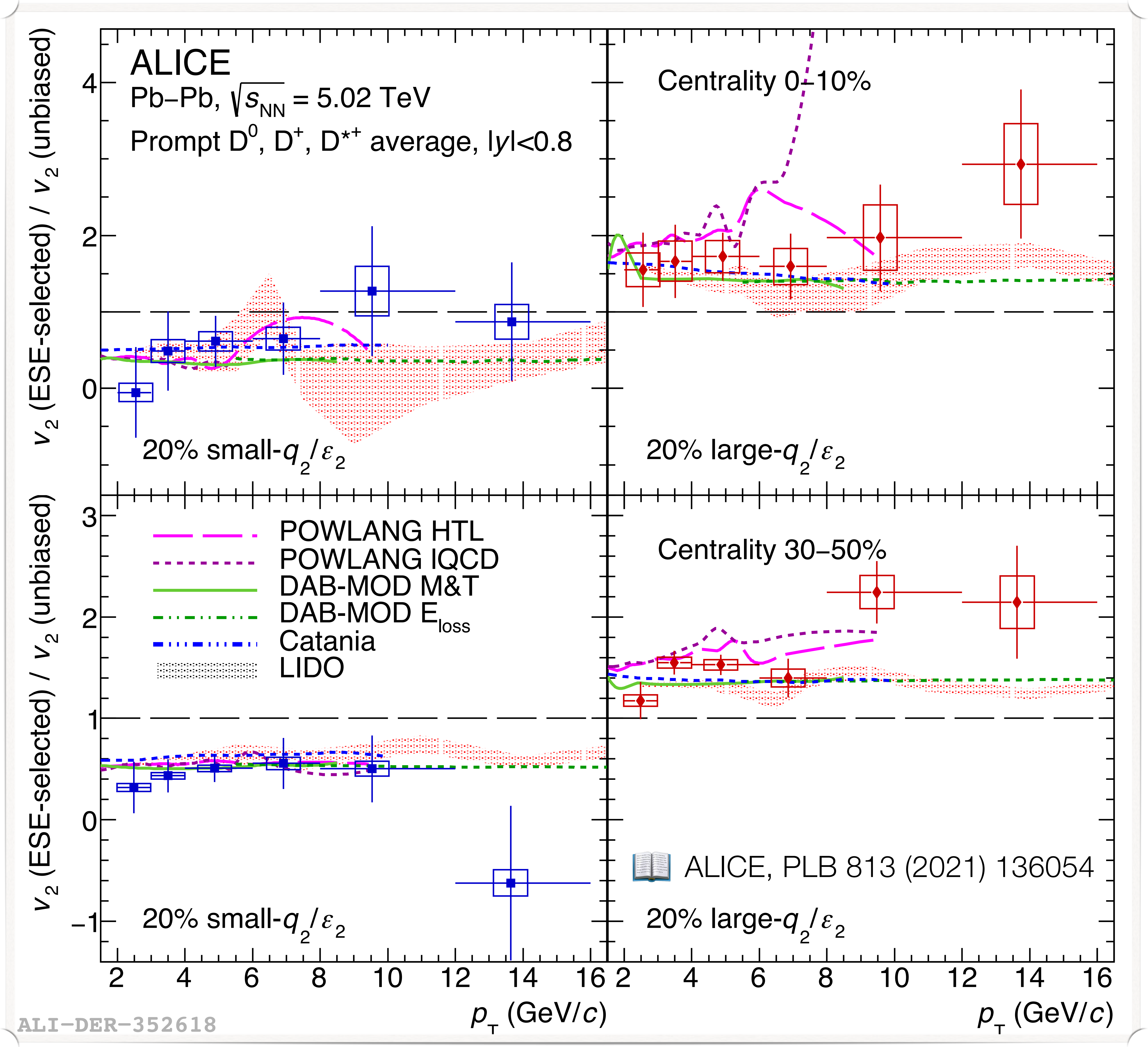


ALICE, PLB 813 (2021) 136054

- D-meson v_2 in ESE-selected sample in 0-10% and 30-50% centrality class
- Results point to a positive correlation between D-meson v_2 and light-hadron v_2
- Models based on charm-quark transport in an hydrodynamically expanding medium reasonably describe the q_2 dependence of elliptic flow

POWLANG: EPJC 79, 494 (2019)
DAB-MOD M&T: PRC 96 064903 (2017)
LIDO: PRC 98 064901 (2018)
CATANIA: PLB 805 135460 (2020)

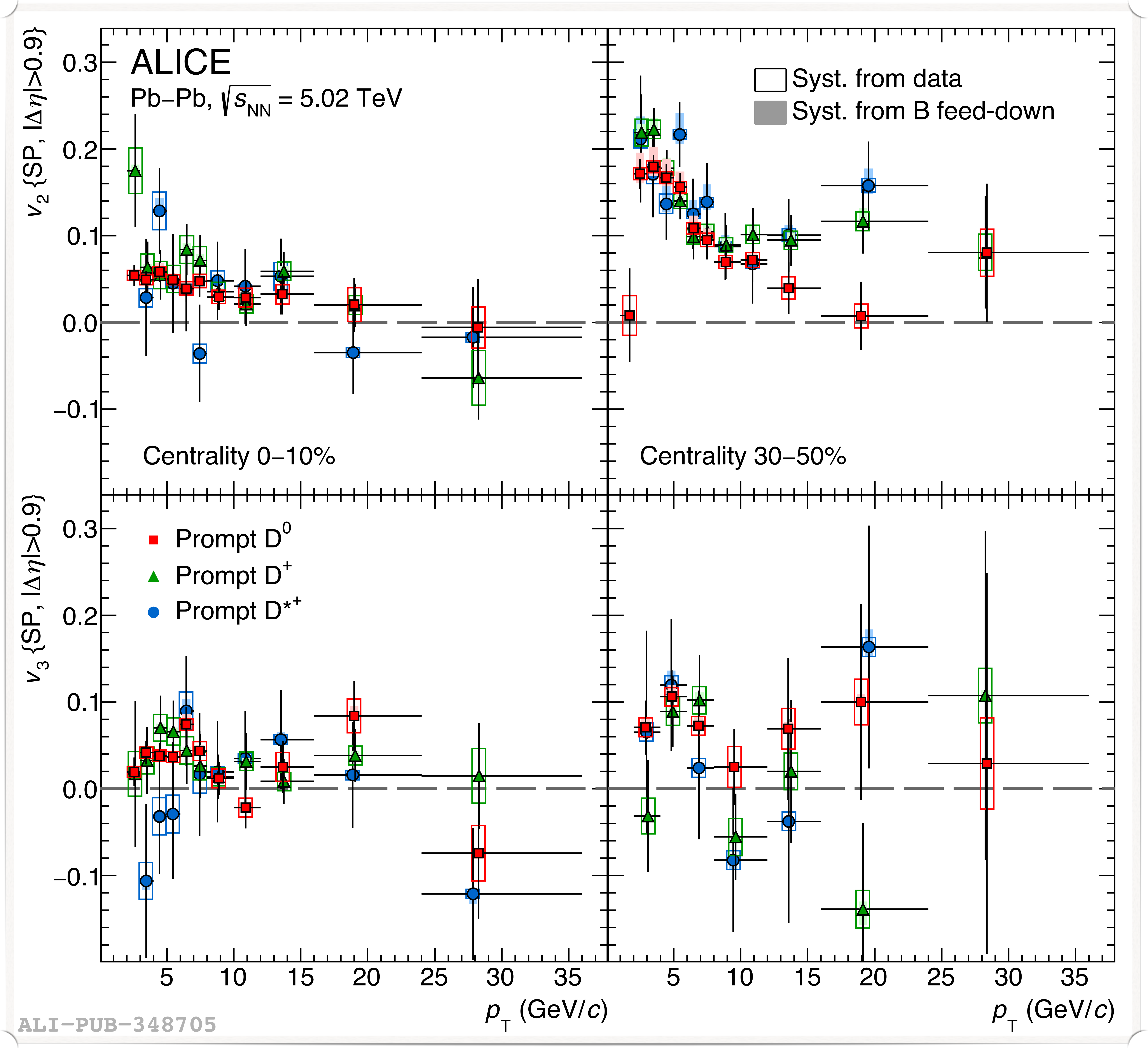
ESE-selected elliptic flow



- **Ratio** v_2(ESE-selected) to v_2(unbiased)
  - ➡ v_2 (large-q_2/small-q_2) $\gtrsim$ v_2 (unbiased) of **about 50%** in both 0-10% and 30-50% centrality
  - ➡ similar **trend** observed for **light-hadron**
- Comparison with **charm-quark transport** models
  - ➡ **different implementations** of the same models give **similar predictions**

POWLANG: EPJC 79, 494 (2019)
LIDO: PRC 98 064901 (2018)
DAB-MOD M&T: PRC 96 064903 (2017)
CATANIA: PLB 805 135460 (2020)

D-meson v_n



- v_2 and v_3 of D^0, D^+ and D^{*+} compatible within uncertainties
- The average v_n of prompt D^0, D^+ and D^{*+} mesons was computed by using the inverse absolute statistical uncertainties as weights

ALICE, PLB 813 (2021) 136054 ALICE-PUBLIC-2020-003

D-meson v_n measurements in Pb-Pb collisions

- D-meson v_n measured at mid-rapidity (|y| < 0.8) using the scalar-product (SP) method

$$v_n\{SP\} = \langle \vec{u}_n \cdot \vec{Q}_n^A \rangle \Big/ \sqrt{\frac{\langle \vec{Q}_n^A \cdot \vec{Q}_n^B \rangle \langle \vec{Q}_n^A \cdot \vec{Q}_n^C \rangle}{\langle \vec{Q}_n^B \cdot \vec{Q}_n^C \rangle}}$$

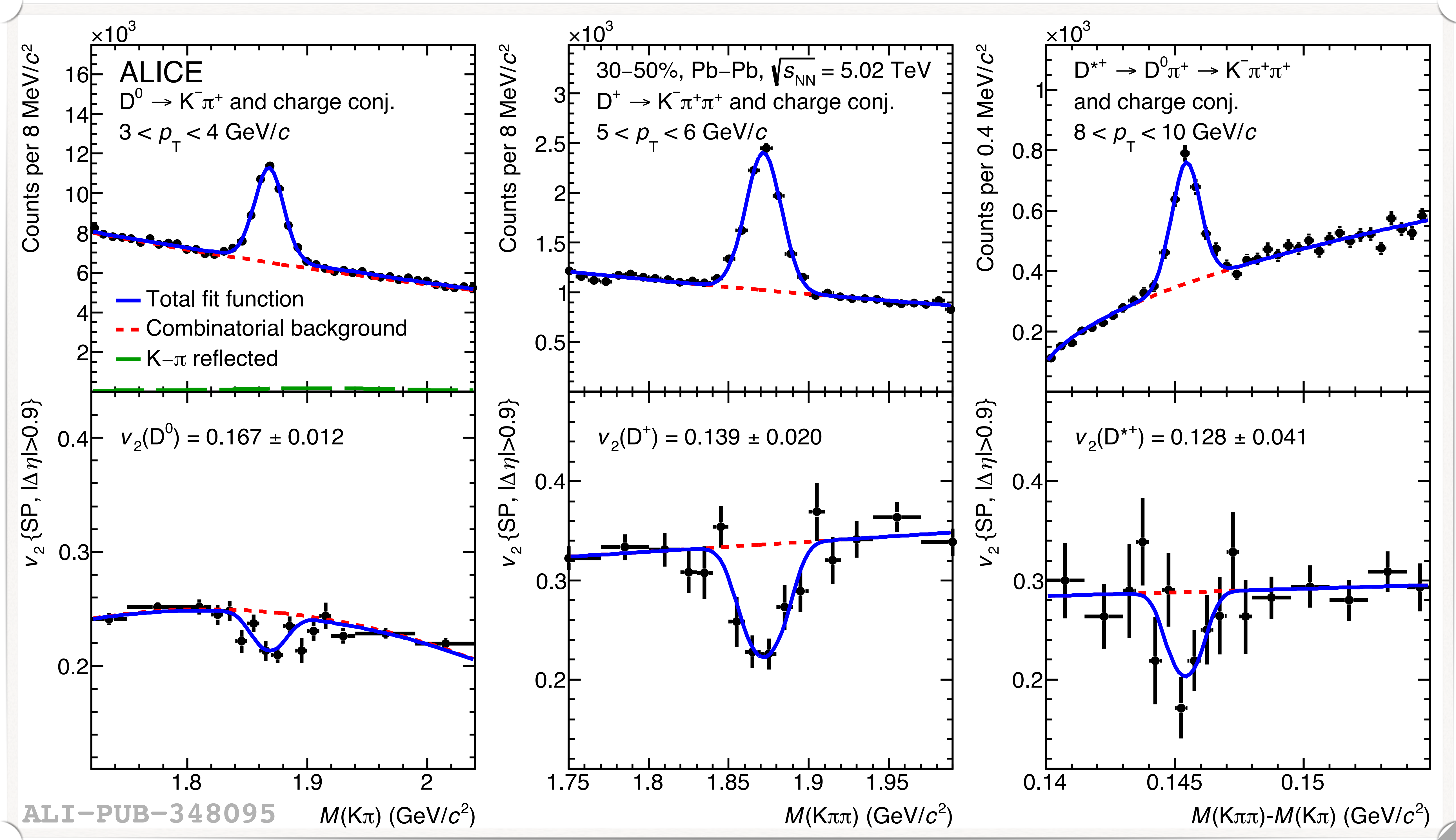
with

$$u_n = e^{in\varphi_D}$$

$$\vec{Q}_n = \sum_{j=1}^{M} e^{in\varphi_j}$$

- The v_n of the signal is extracted from a v_n vs. mass fit:

$$v_n^{tot}(M_D) = v_n^{sig}\frac{S}{S+B} + v_n^{bkg}\frac{B}{S+B}$$



Prompt D-meson v_n

- D-meson v_n from simultaneous fit → D from c-quarks and D from beauty-hadron decays

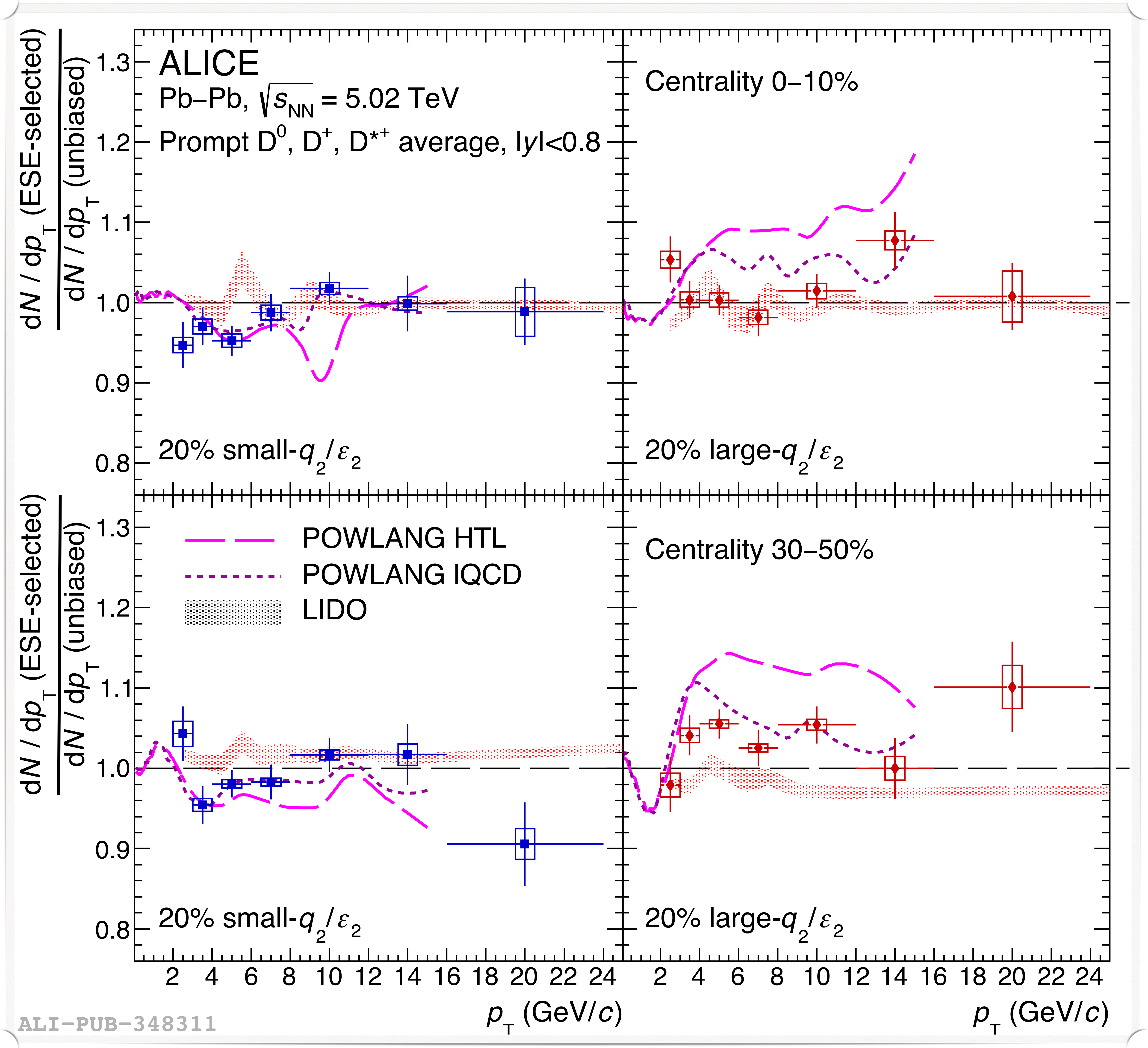
$$v_n^{sig} = f_{prompt} v_n^{prompt} + (1 - f_{prompt}) v_n^{feed-down}$$

- f_{prompt} is the fraction of promptly produced D mesons
  - ➡ estimated with a theory-driven method 📖 JHEP 10 (2018) 174
- v_n coefficients of prompt D mesons obtained assuming

$$v_n^{feed-down} = v_n^{prompt}/2$$

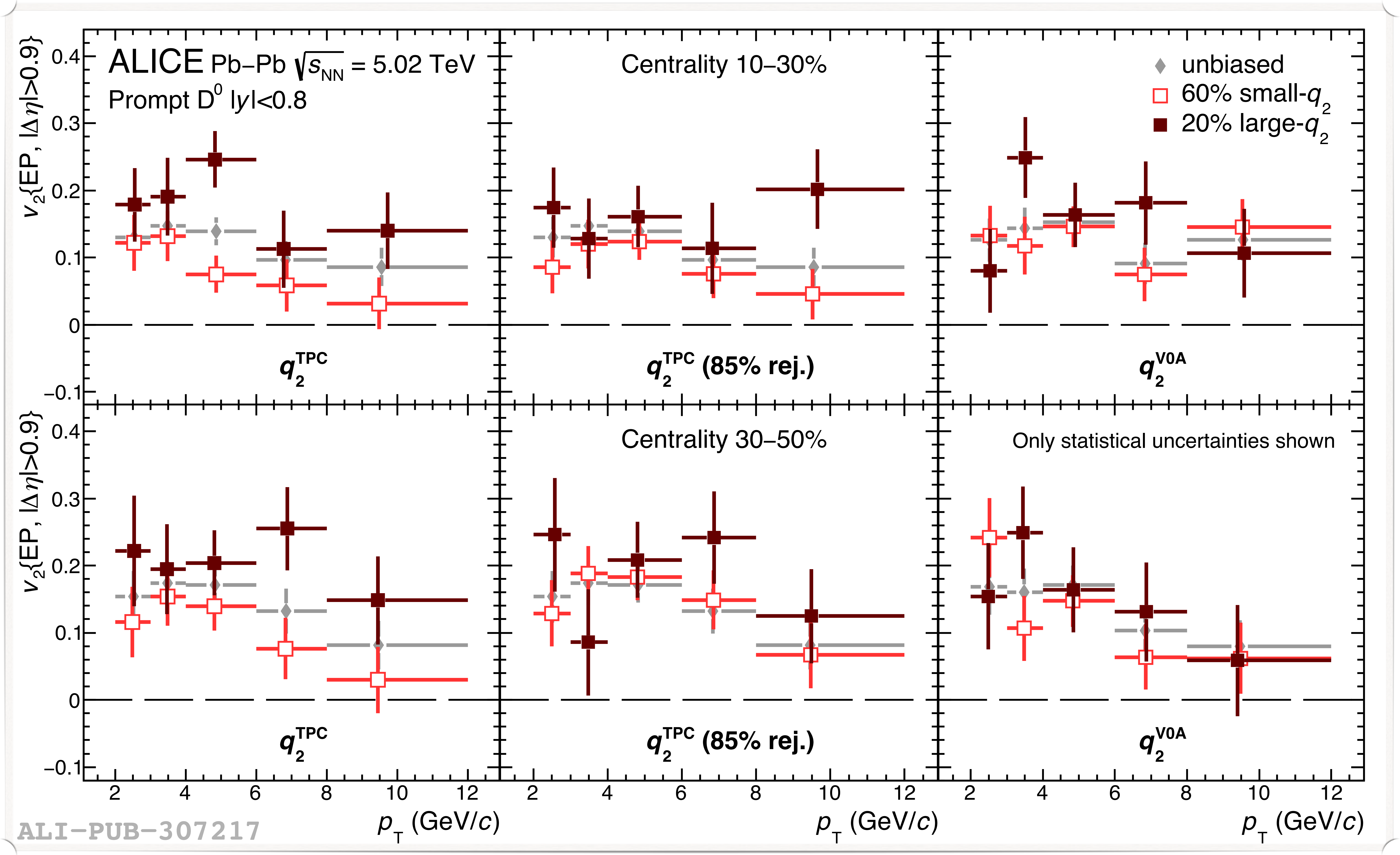
  - ➡ assumption based on experimental results and available model calculations

- D-meson yield ratios in ESE-selected sample
  - ➡ investigate interplay **between elliptic flow and radial flow** (at low/intermediate p_T) **and in-medium energy loss** (high p_T)
- dN/dp_T (ESE)/dN/dp_T (unbiased) **compatible with the unity** within the uncertainties in both centrality classes
  - ➡ indication of no significant modification of the p_T distribution
  - ➡ more firm conclusions with larger data sample



POWLANG: EPJC 79, 494 (2019) LIDO: PRC 98 064901 (2018) ALICE, PLB 813 (2021) 136054

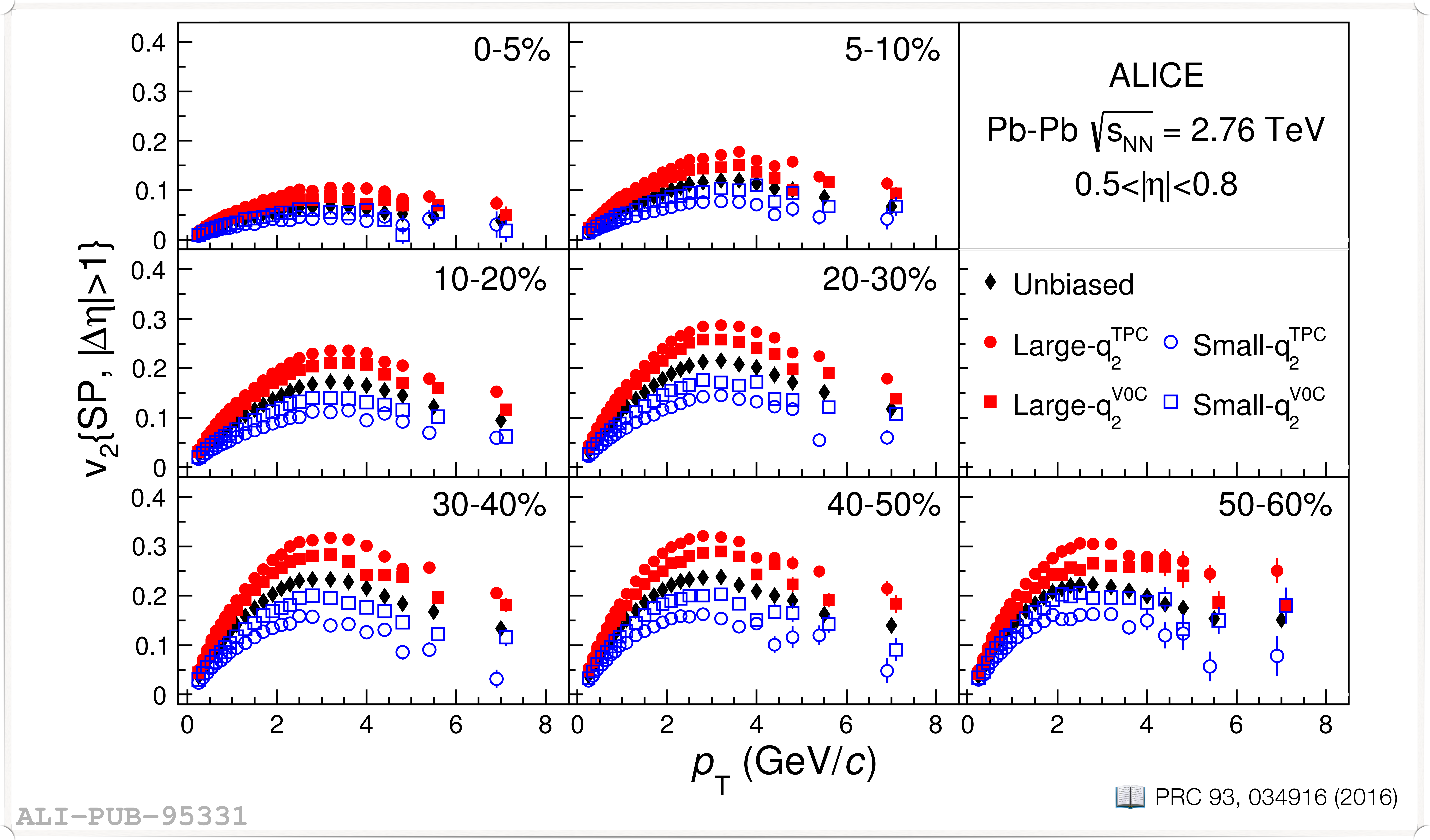
ESE-selected elliptic flow



- D-meson v_2 in ESE-selected sample in 10-30% and 30-50% (2015 dataset)
- Two ESE classes
  - ➡ q_2^{TPC} and q_2^{V0A}
- Investigate possible non-flow effects

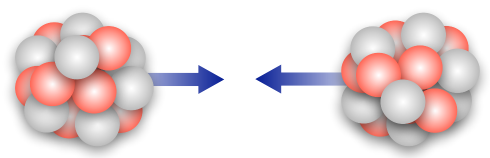
📖 JHEP 02 (2019) 150

Light Flavour: ESE-selected elliptic flow

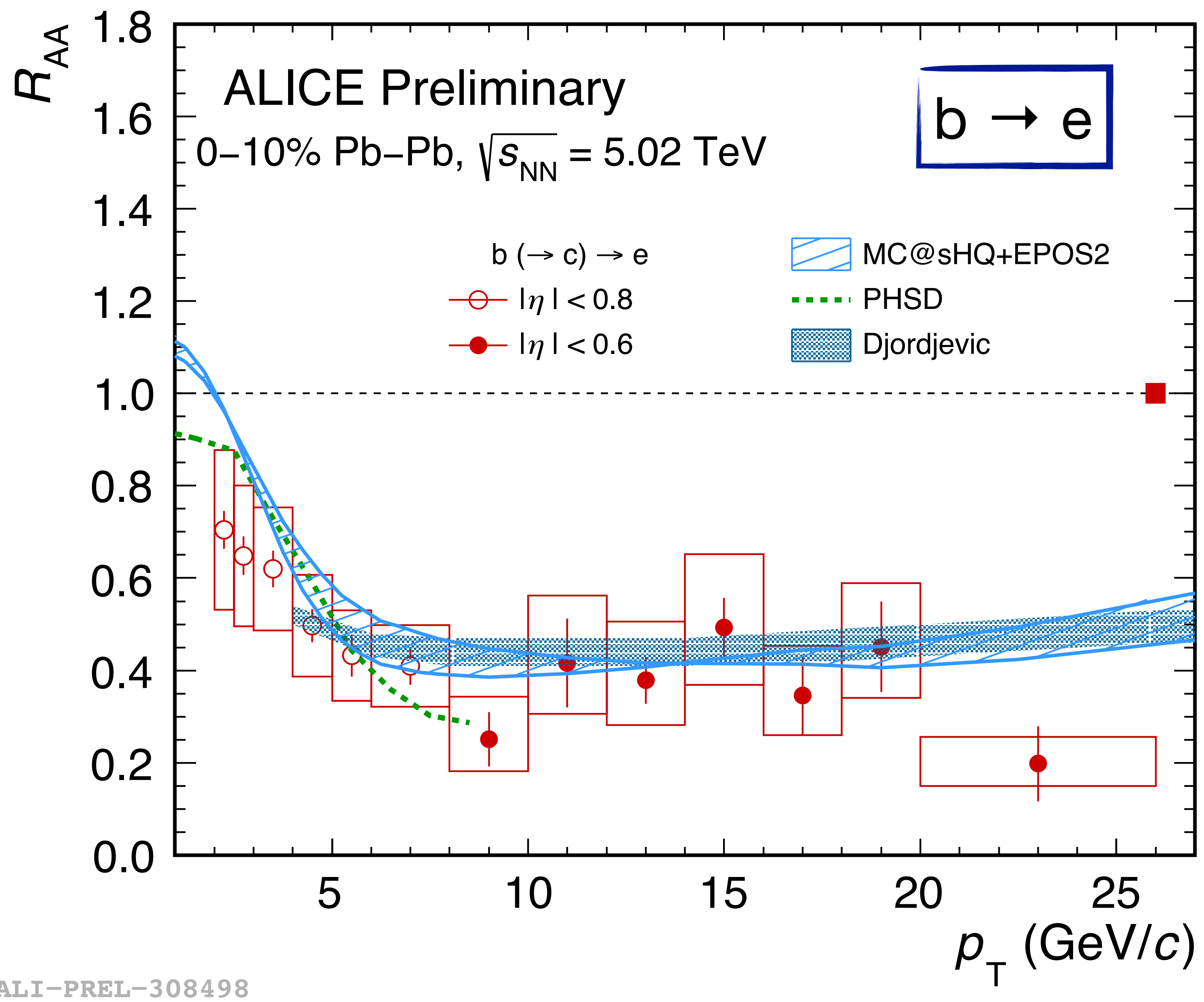


PRC 93, 034916 (2016)

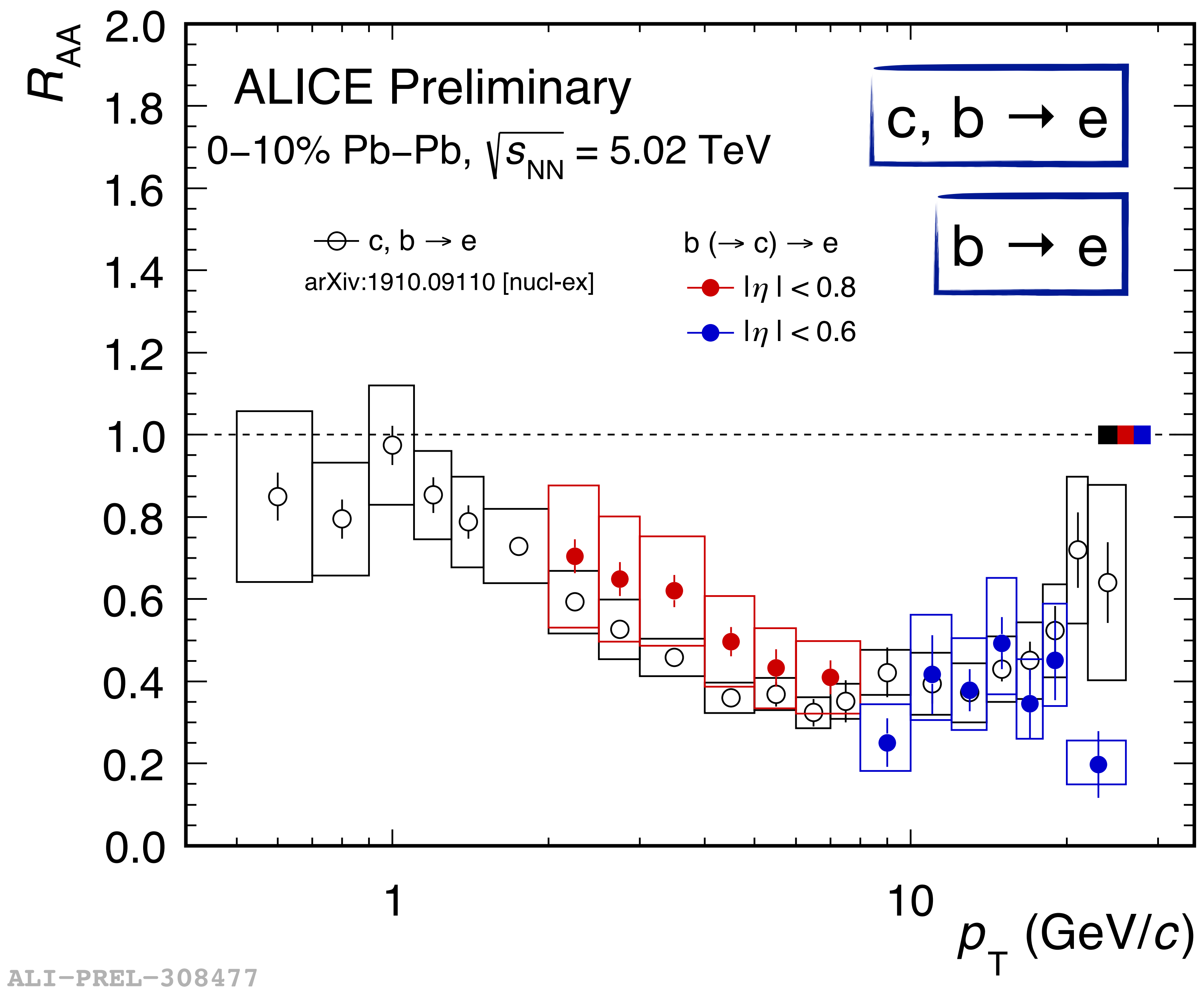
Electrons from beauty hadrons in Pb-Pb collisions



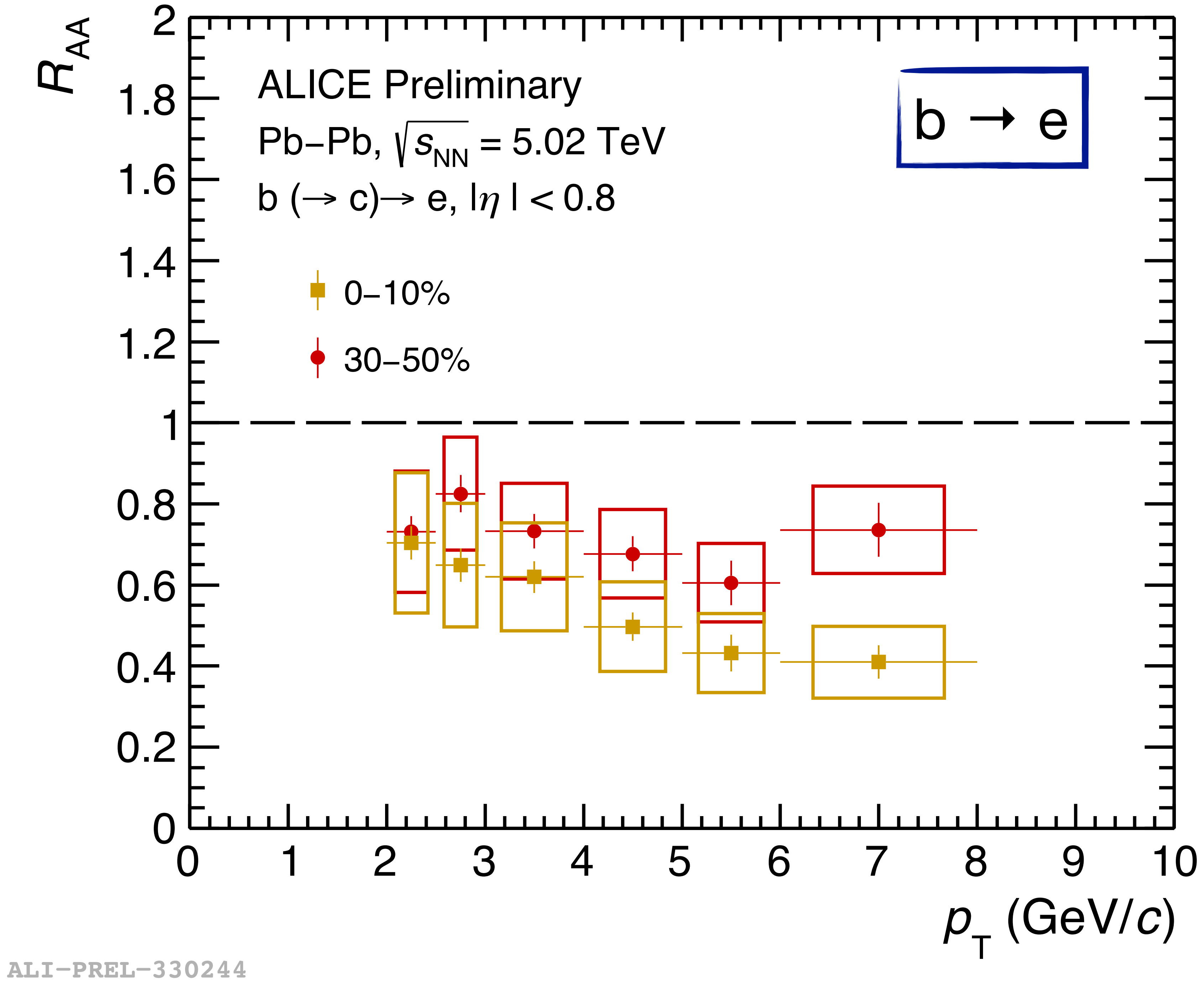
Pb–Pb $\sqrt{s_{NN}}$ = 5.02 TeV



ALI−PREL−308498



ALI−PREL−308477



ALI−PREL−330244

- R_{AA} described by models which include collisional and radiative energy loss
  - ➡ low p_T: hint of less suppression of b → e w.r.t. c, b → e
  - ➡ high p_T: R_{AA} merge → beauty contribution dominant
- Indication of centrality dependence of in-medium energy loss in beauty sector

📖 MC@sHQ+EPOS: PRC 89, 014905 (2014) 📖 PHSD: PRC 92, 014910 (2015) 📖 Djordjevic: PLB 791 (2019) 236-241