



ALICE



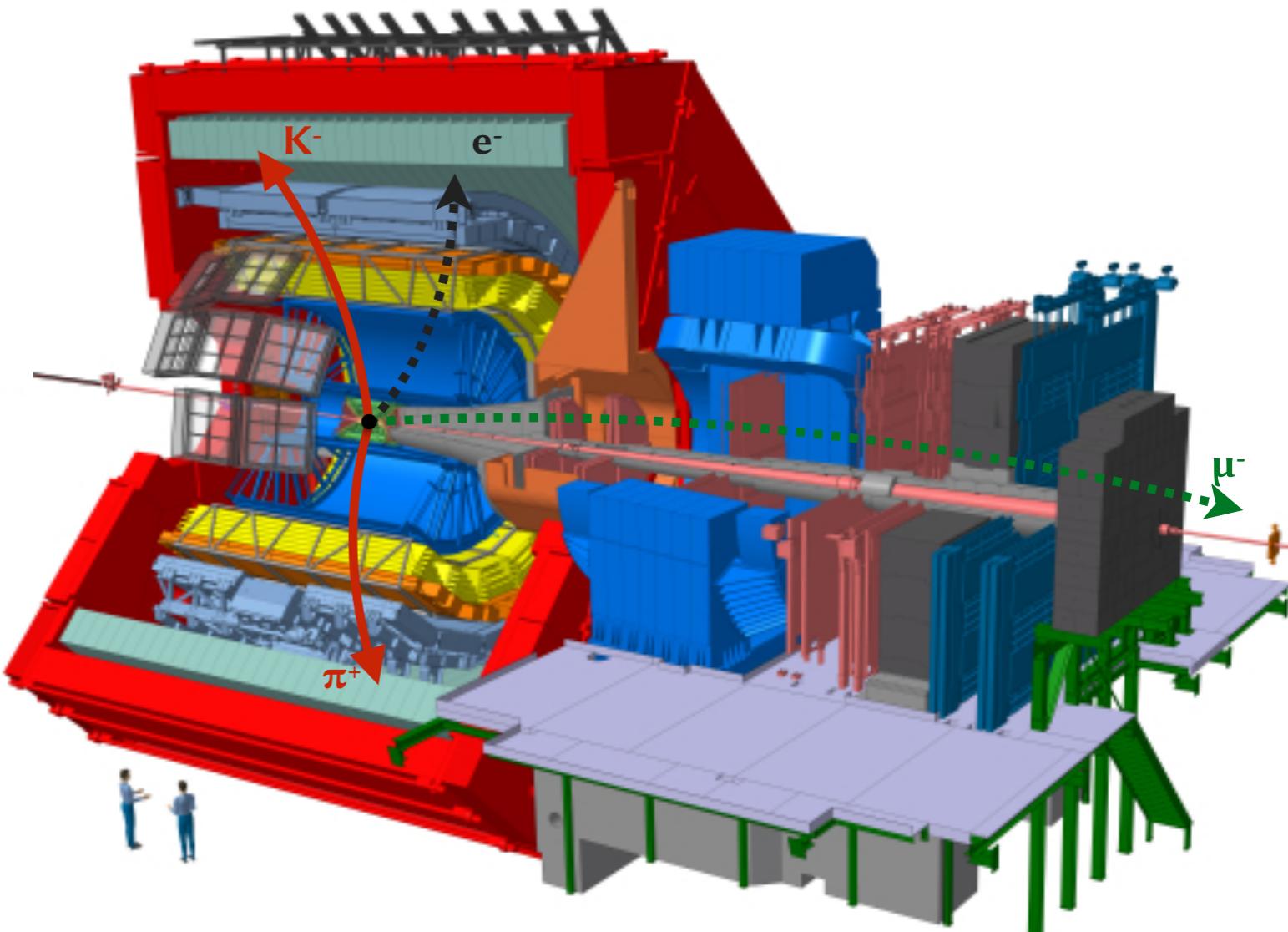
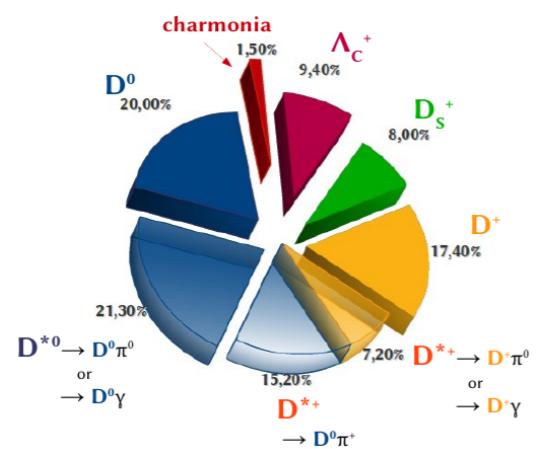
D-meson measurements with ALICE at central rapidity

Open heavy-flavour in ALICE:

HF-decay electrons: $c, b \rightarrow e^\pm, J/\Psi + X$ ($|\eta| < 0.8$)

HF-decay muons: $c, b \rightarrow \mu^\pm + X$ ($-4 < \eta < -2.5$)

Open charm: $D^0, D^+, D^{*+}, D_s^+ \rightarrow \pi^\pm, K^\pm$ ($|\eta| < 0.9$)





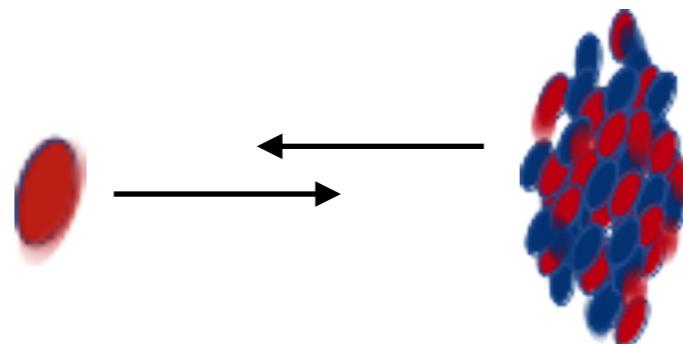
Outline

Heavy-quark specificities

proton-lead results

ALICE-PUBLIC-2017-008

Initial Stages preliminaries (September 2017)

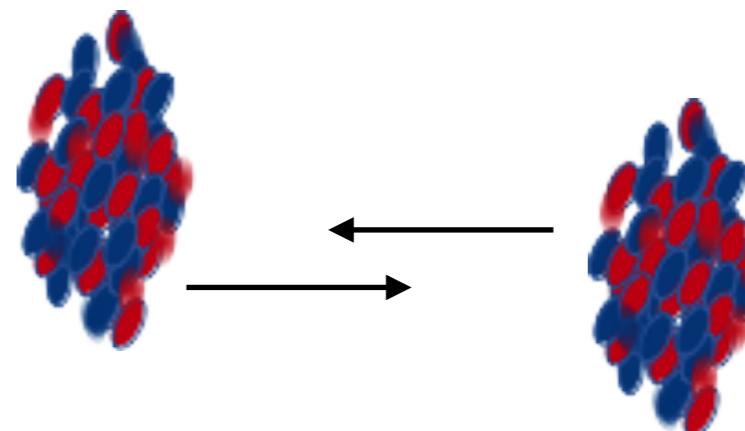


lead-lead results

ALICE-PUBLIC-2017-003

arXiv:1707.01005

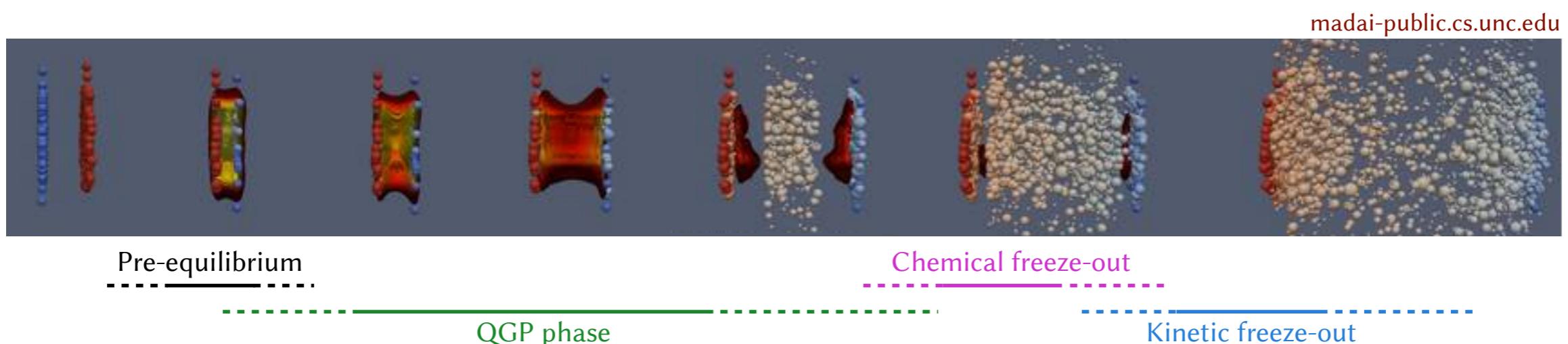
Initial Stages preliminaries (September 2017)





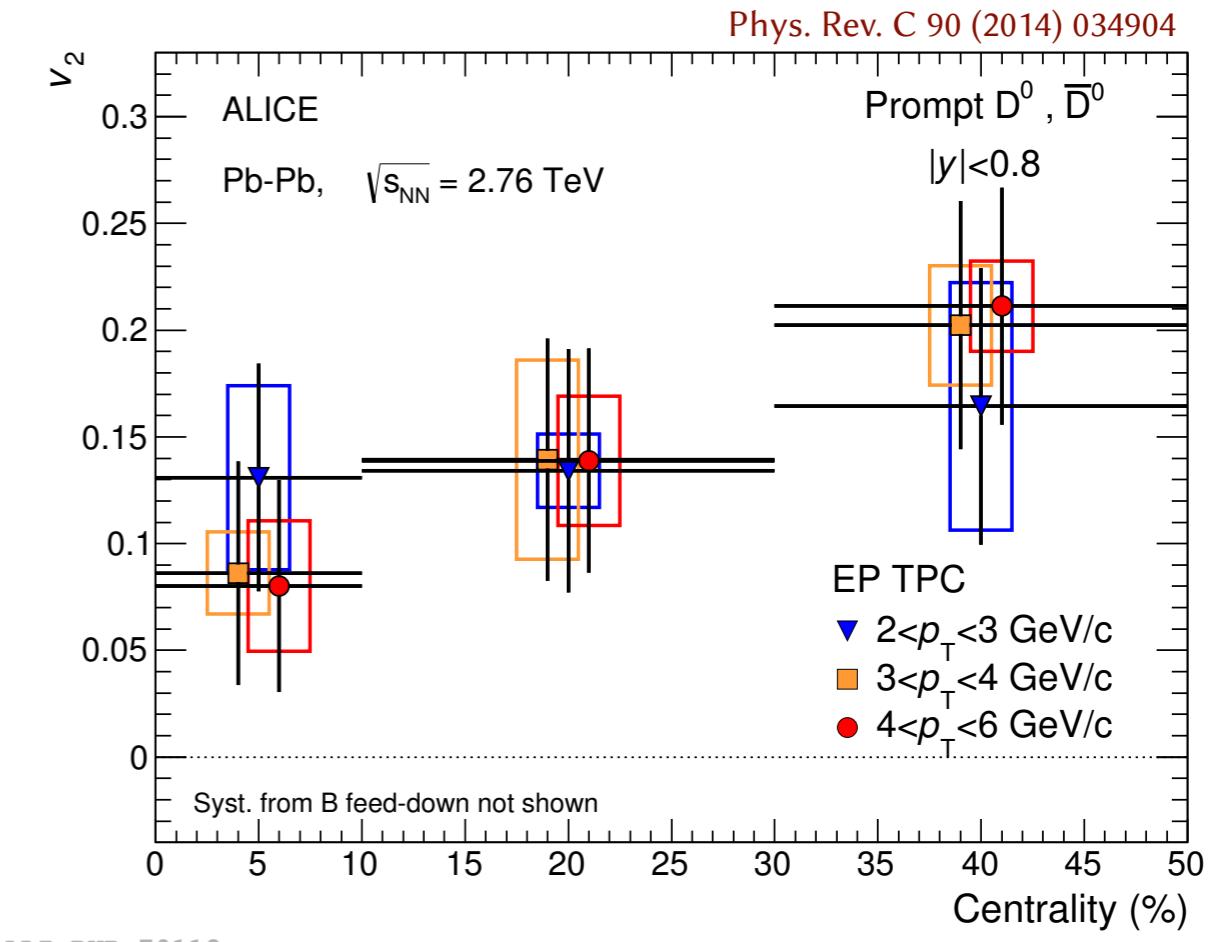
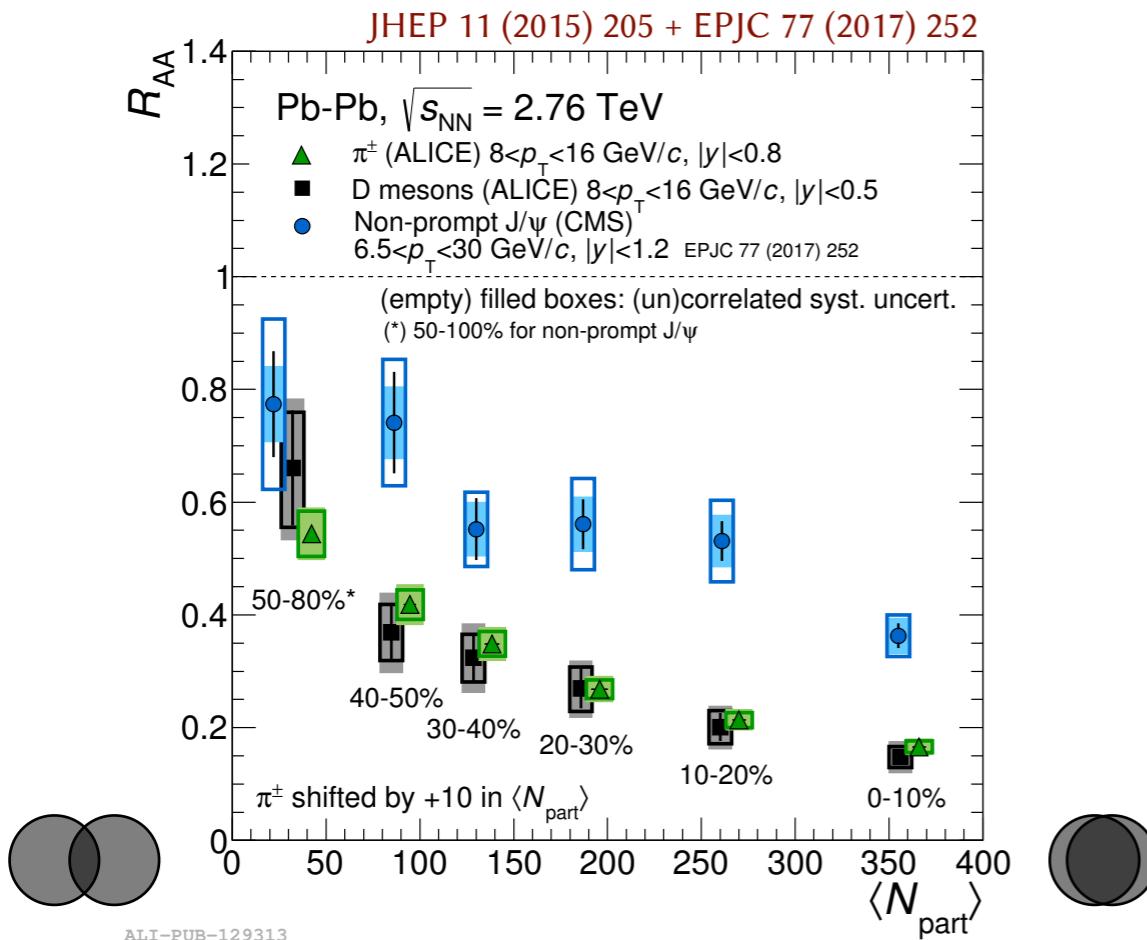
Heavy-quark specificities

- ✓ Produced in hard scattering (high- Q^2) processes: pQCD calculations down to 0 GeV/c
- ✓ Short formation time: produced before the QGP formation
 $\Delta t_c < 1/(2m_c) \sim 0.1 \text{ fm}/c < \tau_{\text{QGP}} \sim 0.3 - 1 \text{ fm}/c$ at LHC
- ✓ Negligible annihilation rate: experience the *whole* collision history
- ✓ Interact with the medium constituents: via elastic (collisions) and inelastic (radiations) processes
- ✓ Hadronize: via fragmentation and coalescence processes?





Heavy-quark specificities



Large suppression of **D mesons** (D^+ , D^0 , D^{*+}) in Pb-Pb collisions:

- Heavy quarks affected by energy loss, medium transport properties, size and temperature

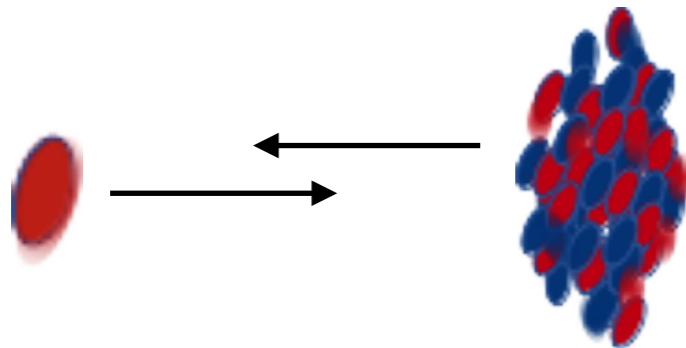
$$R_{AA} = \frac{(dN/dp_T)_{AA}}{\langle T_{AA} \rangle \times (d\sigma/dp_T)_{pp}}$$

Comparison of **prompt D-mesons** with **charged π^\pm** and **non-prompt J/ ψ** :

- Colour charge ($\Delta E_g > \Delta E_{u,d,s}$) and mass ($\Delta E_c > \Delta E_b$) dependence of energy loss

Positive v_2 of D mesons for $2 < p_T < 6$ GeV/c (5.7 σ):

- Participation to the collective expansion, thermalisation?



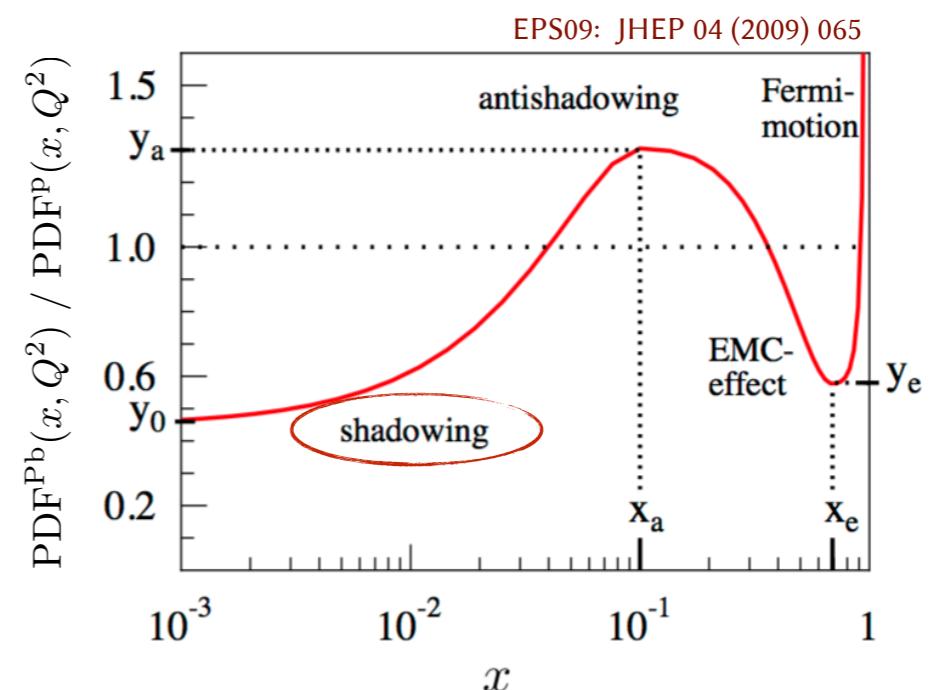
proton-lead

Cold nuclear matter effects

- Modification of nuclear PDF with respect to free nucleon?
- k_T broadening?
- Coherent energy loss?

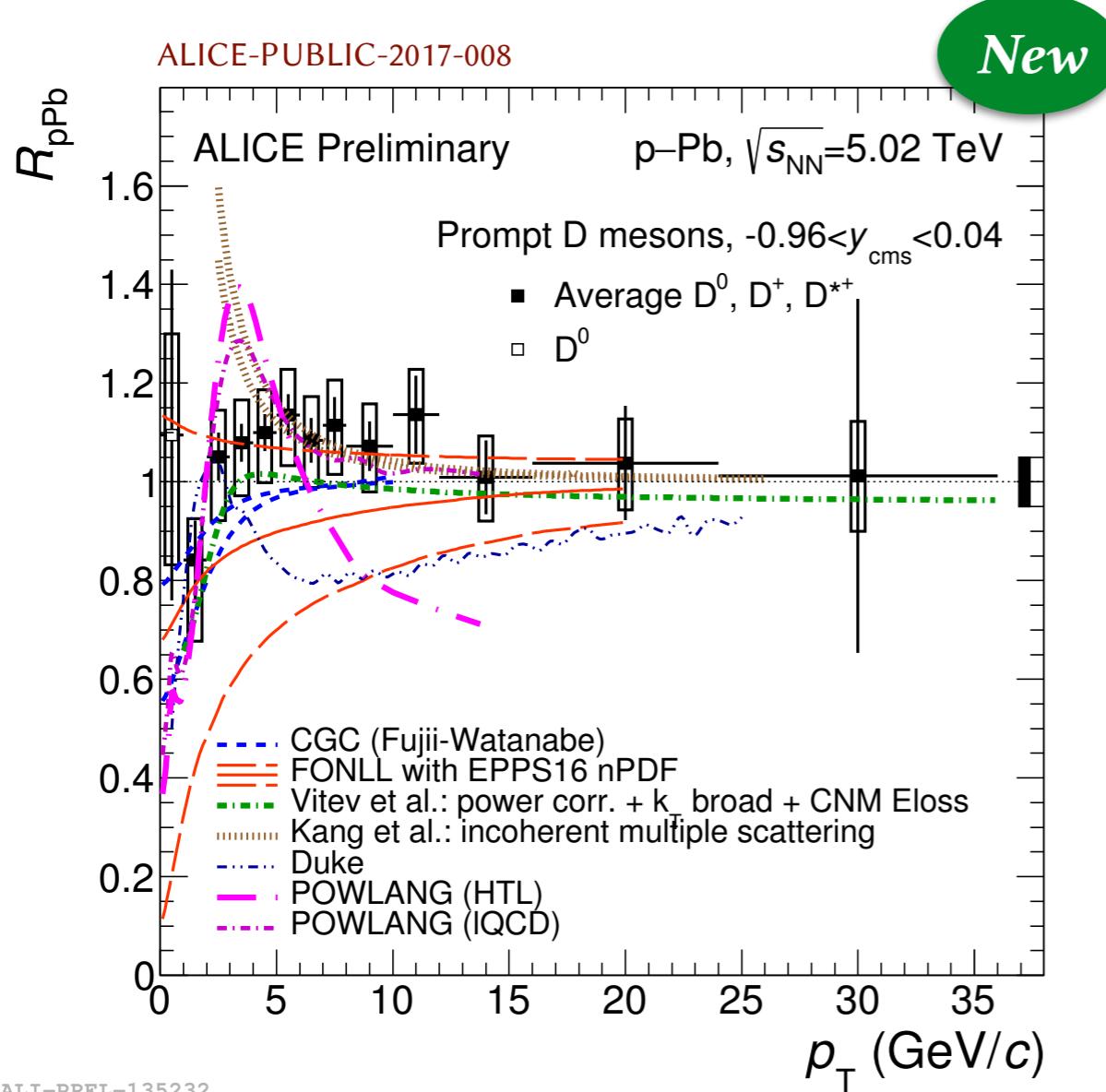
Are hadronization mechanisms affected?

Final-state effects, collectivity à la QGP?





R_{pPb} of D mesons (2016 data)



New Run 2 (2016) p-Pb data sample:

6 times larger sample than the Run 1 (2013)

- Better precision of p-Pb measurements
- Measurements extended to higher p_{T}

Public note: ALICE-PUBLIC-2017-008

Nuclear modification factor:

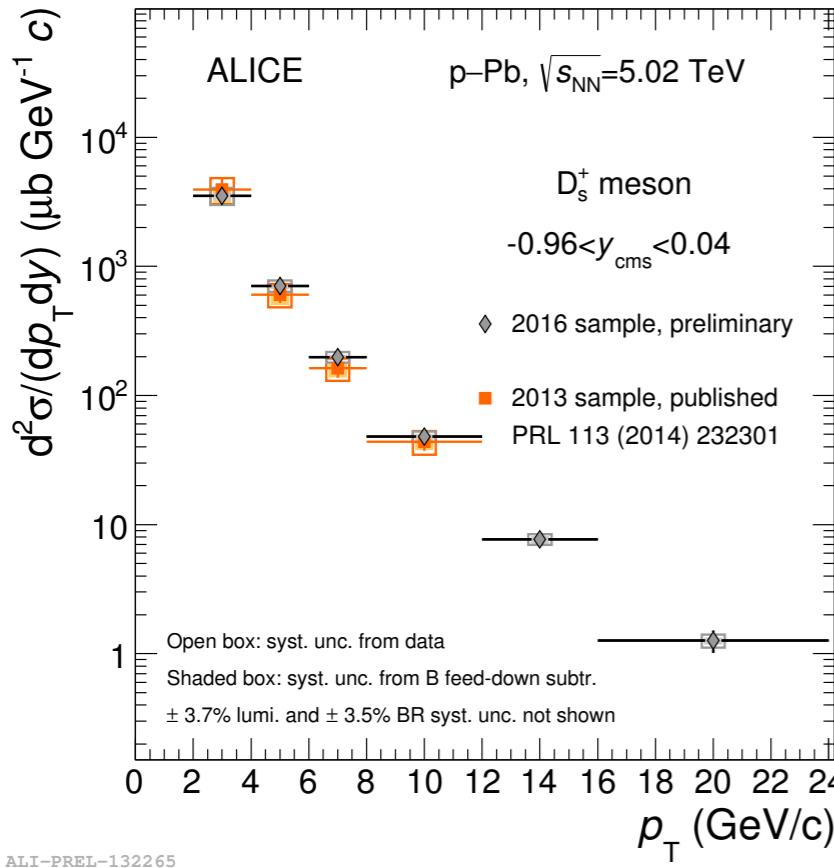
$$R_{\text{pA}} = \frac{(\text{d}\sigma/\text{d}p_{\text{T}})_{\text{pA}}}{A \times (\text{d}\sigma/\text{d}p_{\text{T}})_{\text{pp}}}$$

Minimum-bias $R_{\text{pPb}} \sim 1$:

- Small/negligible Cold Nuclear Matter (CNM) effects at high p_{T}
- Transport models (**Duke**, **POWLANG**), assuming QGP formation in p-Pb, disfavoured by data
- Models assuming CNM effects (nPDF, k_{T} broadening, E_{loss} , ...) reproduce the measurement

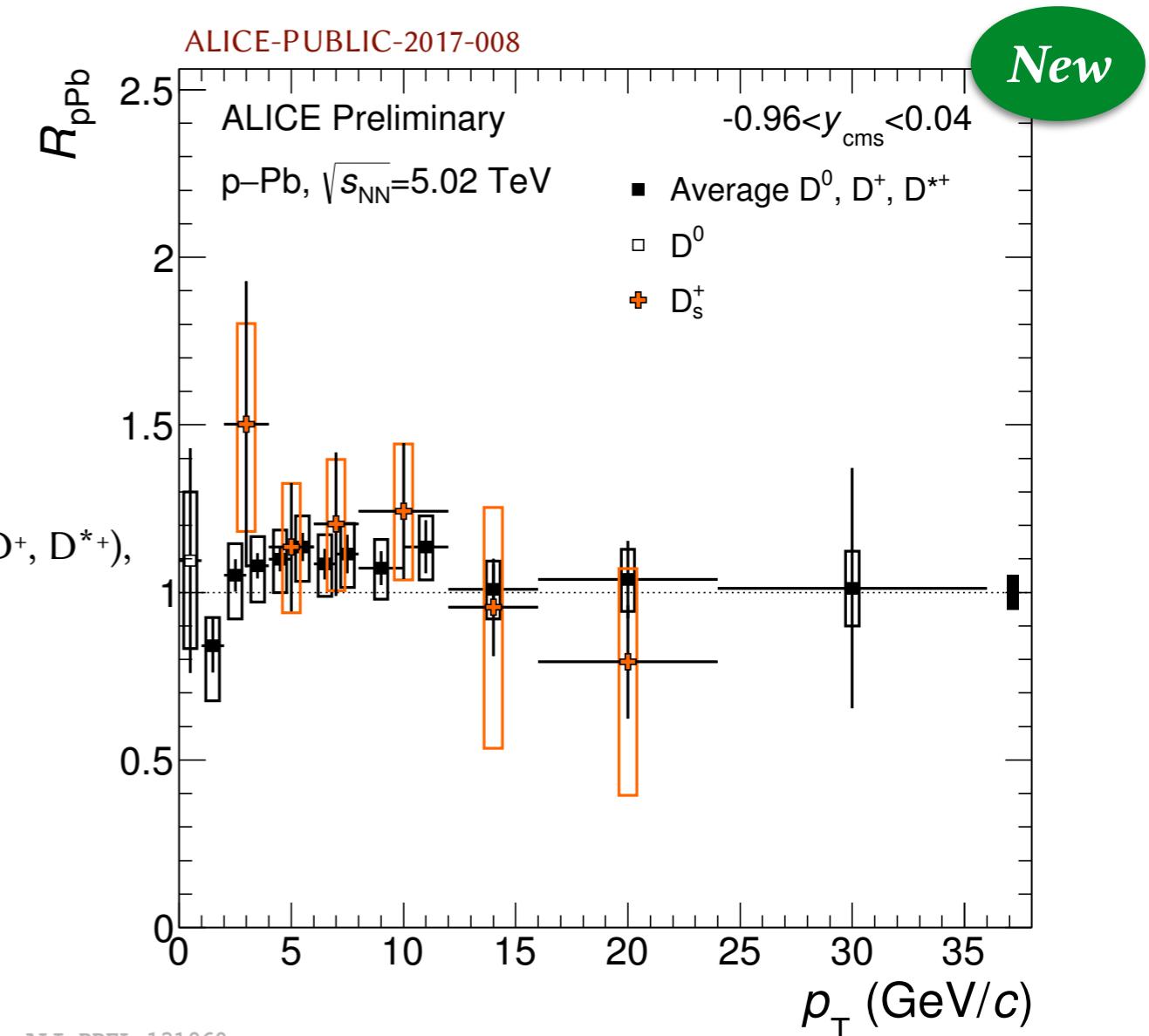


Strange vs. non-strange D mesons



D_s^+ measurement performed by Strasbourg:

- p_T range extended from 12 to 24 GeV/c
- Relative statistical uncertainties of p-Pb cross-section divided by >2
- Main uncertainties coming from the absence of pp reference

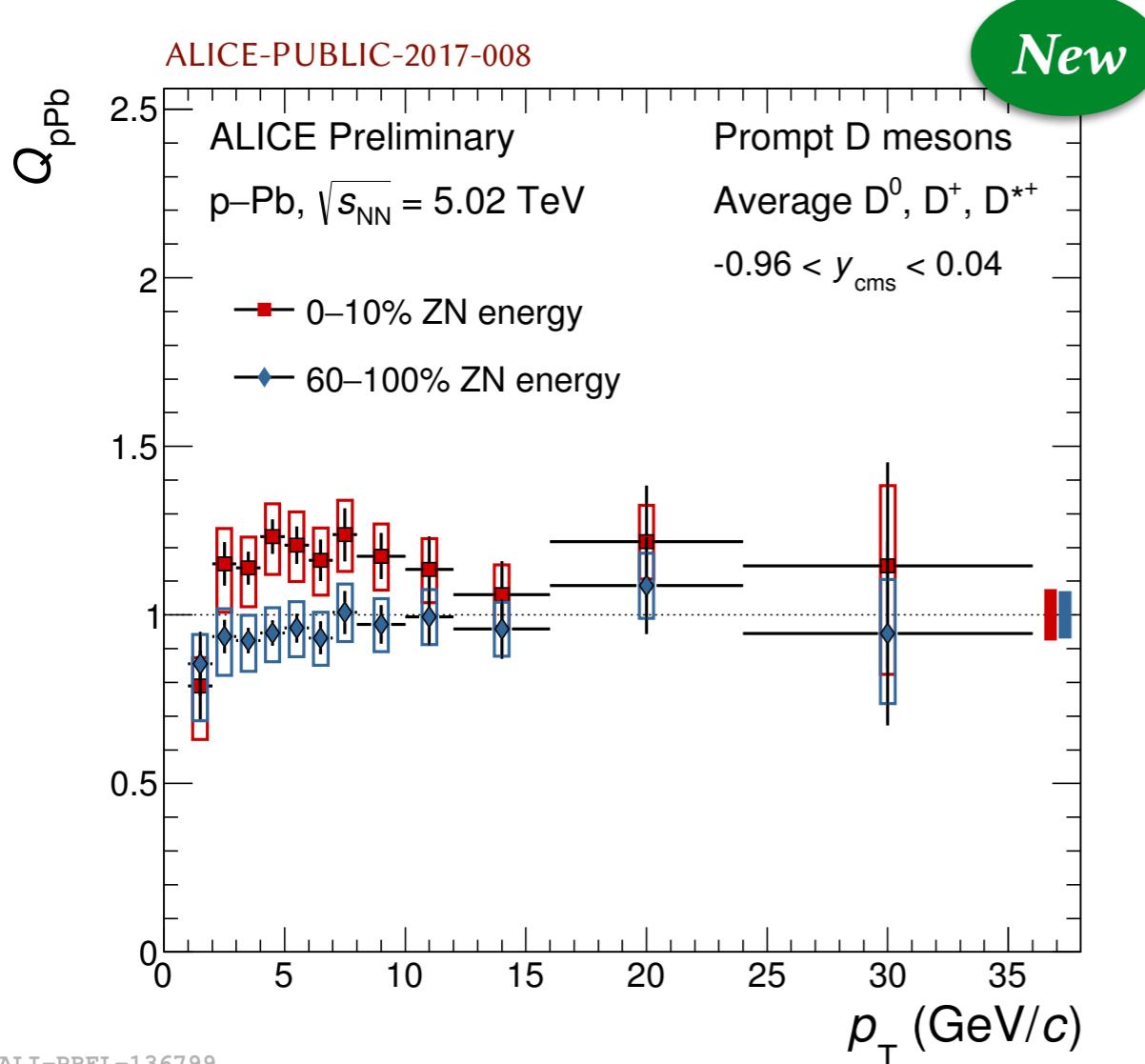


Strange vs. non-strange D mesons

→ No difference between R_{ppb} of D_s^+ and average (D^0 , D^+ , D^{*+}), with the current uncertainties



Centrality dependence of R_{pPb}



$$Q_{\text{pA}}^{\text{cent}} = \frac{(\text{d}N/\text{d}p_{\text{T}})_{\text{pA}}^{\text{cent}}}{\langle T_{\text{pA}} \rangle^{\text{cent}} \times (\text{d}\sigma/\text{d}p_{\text{T}})_{\text{pp}}}$$

Nuclear modification factor VS. centrality:

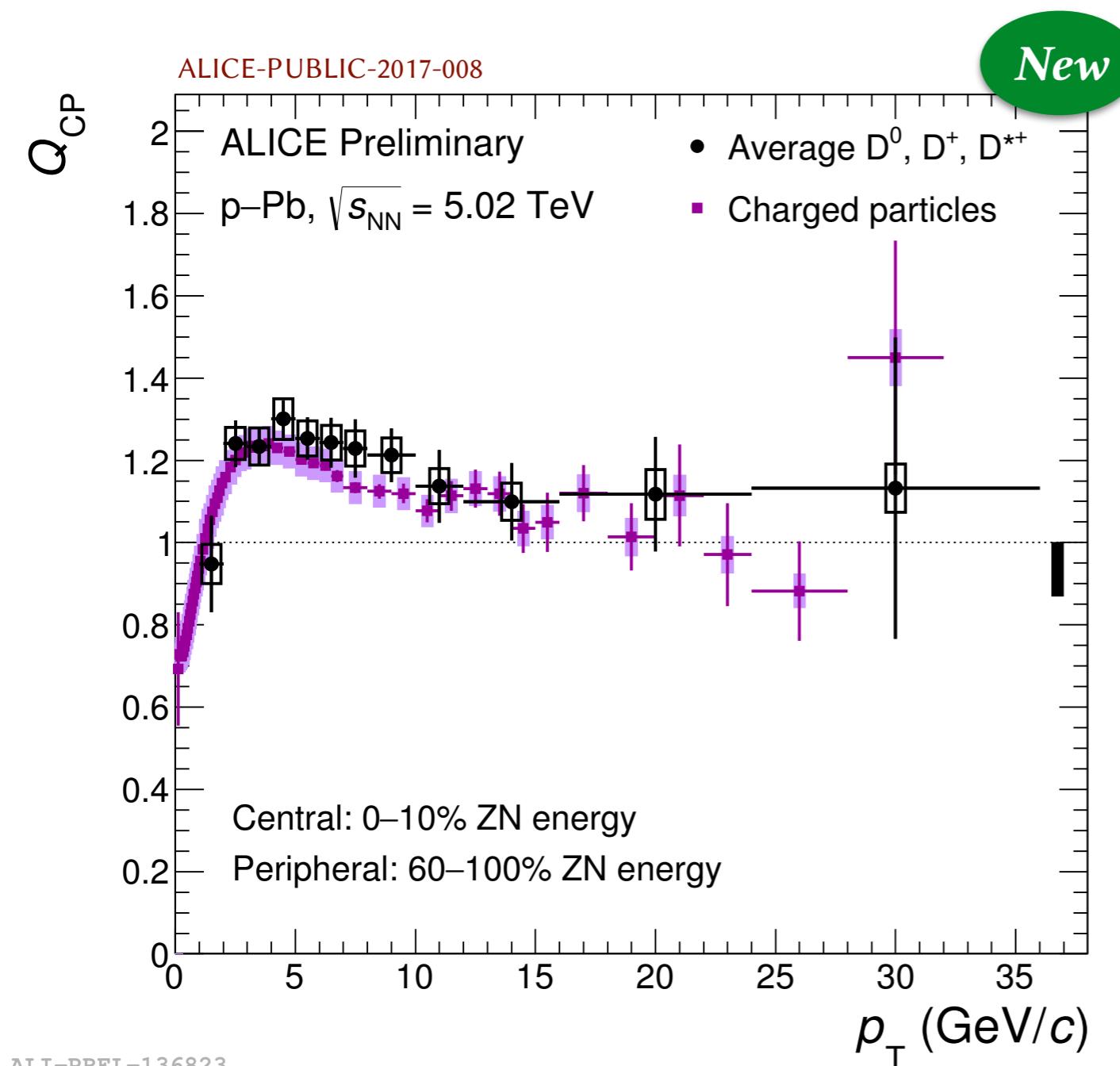
- Centrality intervals defined by the Zero-degree Neutron calorimeter (ZN): 112.5m from Interaction Point, $|\eta|>8.7$
- $Q_{\text{pPb}}^{0-10\%} \sim Q_{\text{pPb}}^{60-80\%}$: No centrality dependence, within uncertainties

Awaiting for more precise pp reference:

- CNM effects are expected to be dominant at low p_{T} but...
 - ... largest measurement uncertainties sit at low p_{T}
- Large pp data sample at $\sqrt{s} = 5 \text{ TeV}$ expected at the end of the year



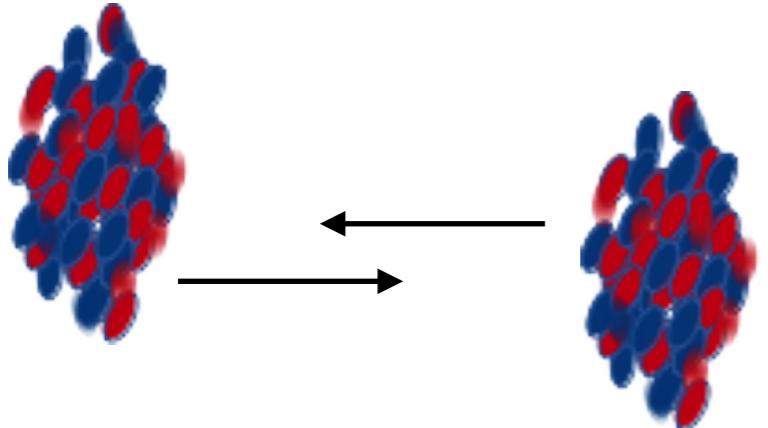
Central-to-peripheral ratio



$$Q_{\text{CP}} = \frac{(\text{d}N/\text{d}p_T)_{\text{pA}}^{0-10}/\langle T_{\text{pA}} \rangle^{0-10}}{(\text{d}N/\text{d}p_T)_{\text{pA}}^{60-100}/\langle T_{\text{pA}} \rangle^{60-100}}$$

Q_{CP} of D mesons is independent of the pp reference:

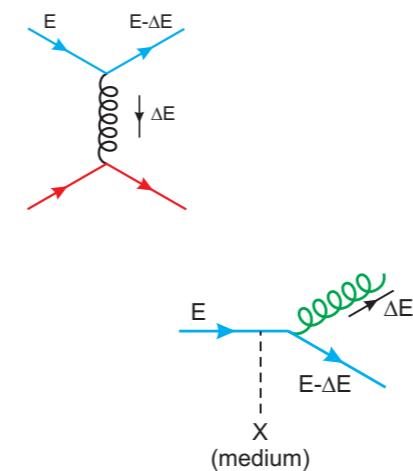
- Average value of Q_{CP} larger than unity in $3 < p_T < 8 \text{ GeV}/c$?
Only by 1.5 standard deviation
- Similar behaviour for **charged particles**



lead-lead

Parton energy loss in the medium

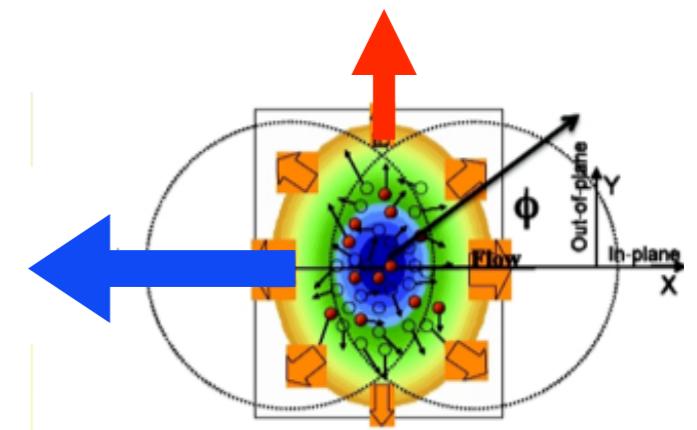
- Colour-charge dependence (Casimir factor)
- Mass dependence (dead-cone effect)



Collectivity

- Transport properties of the medium
- Thermalisation

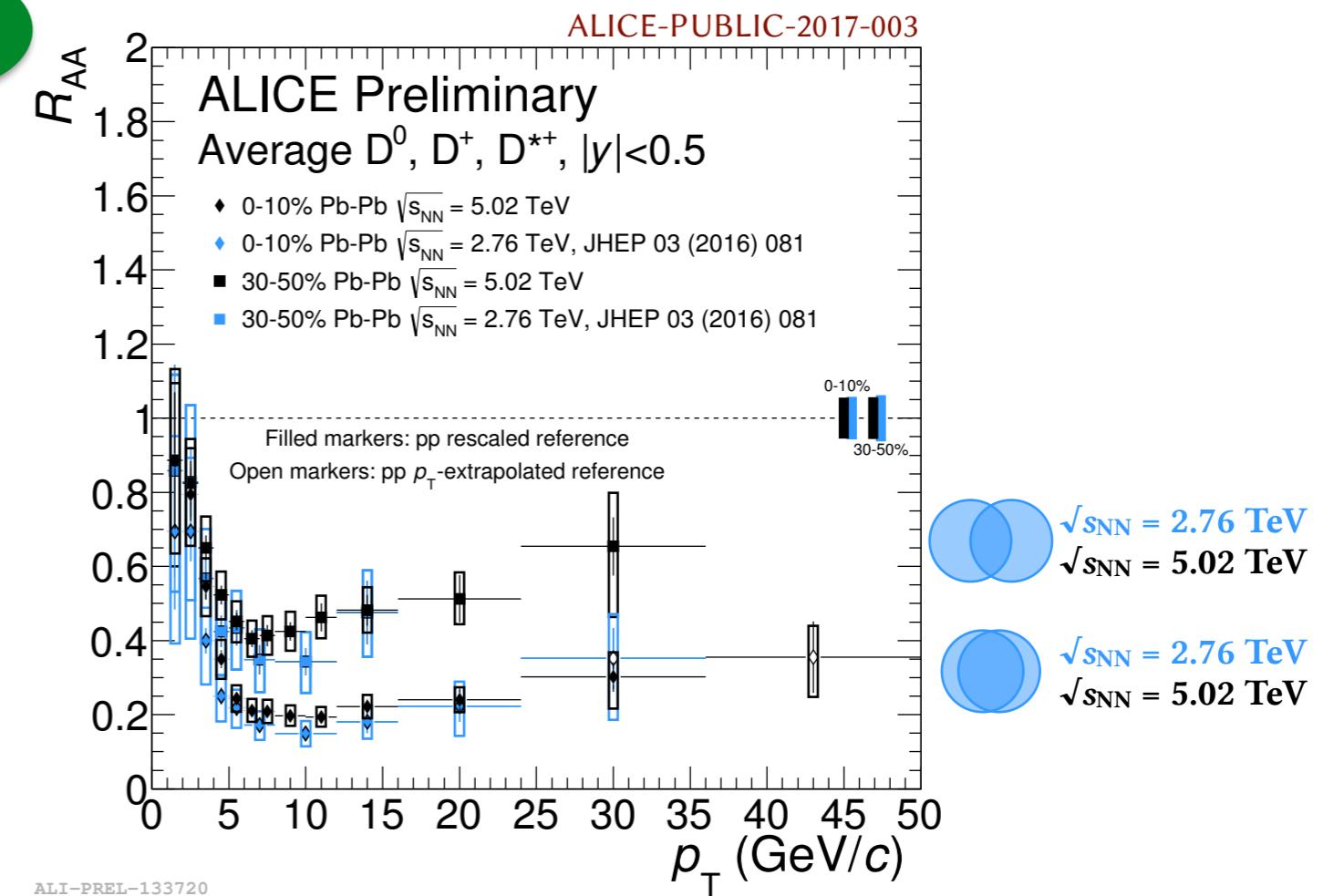
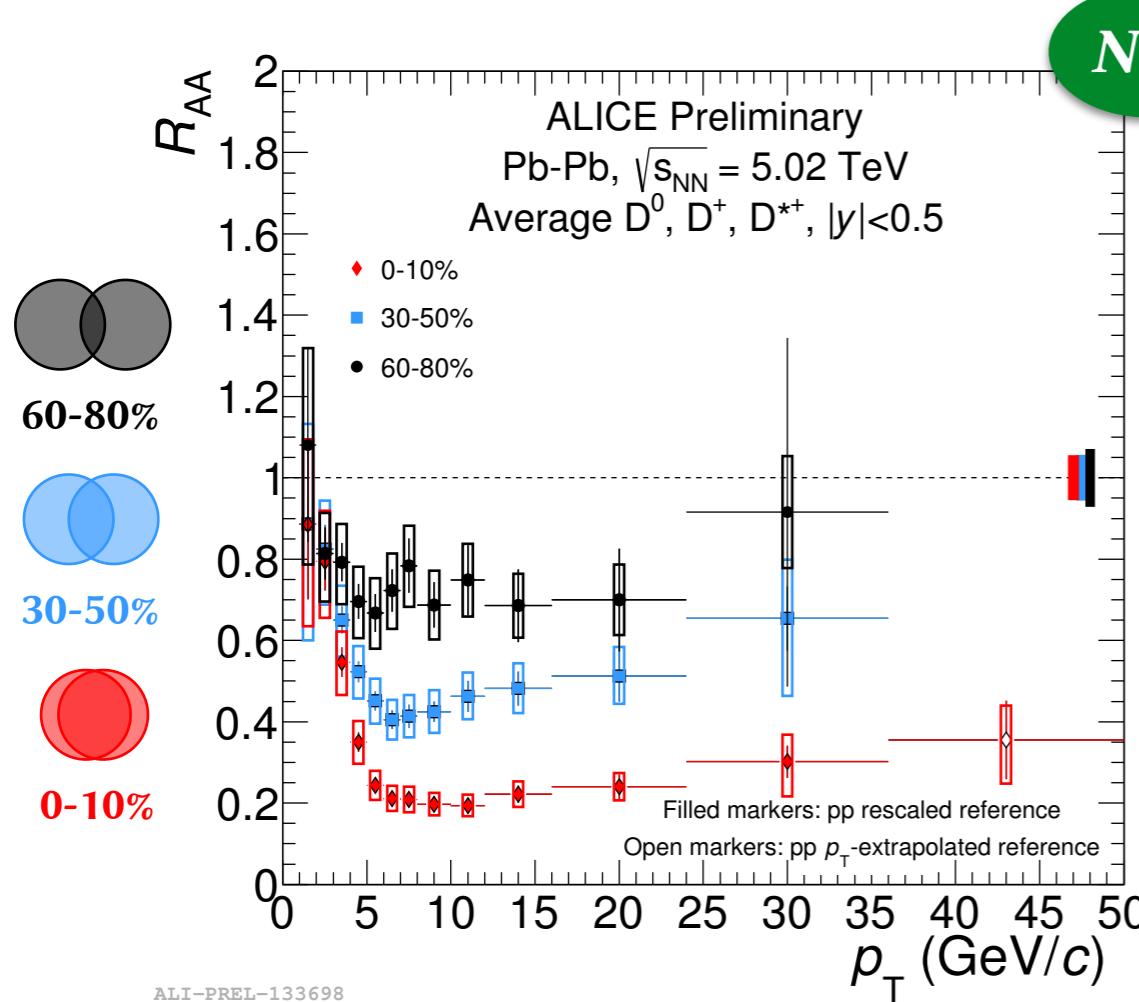
Hadronization: sign of coalescence



madai-public.cs.unc.edu



Nuclear modification factor



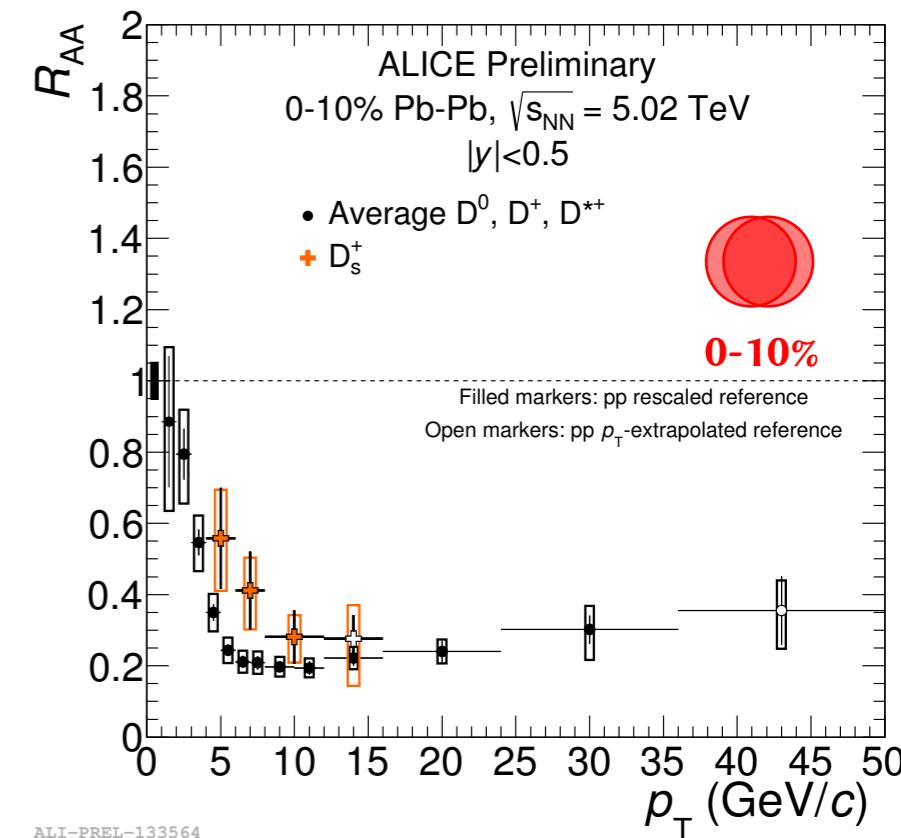
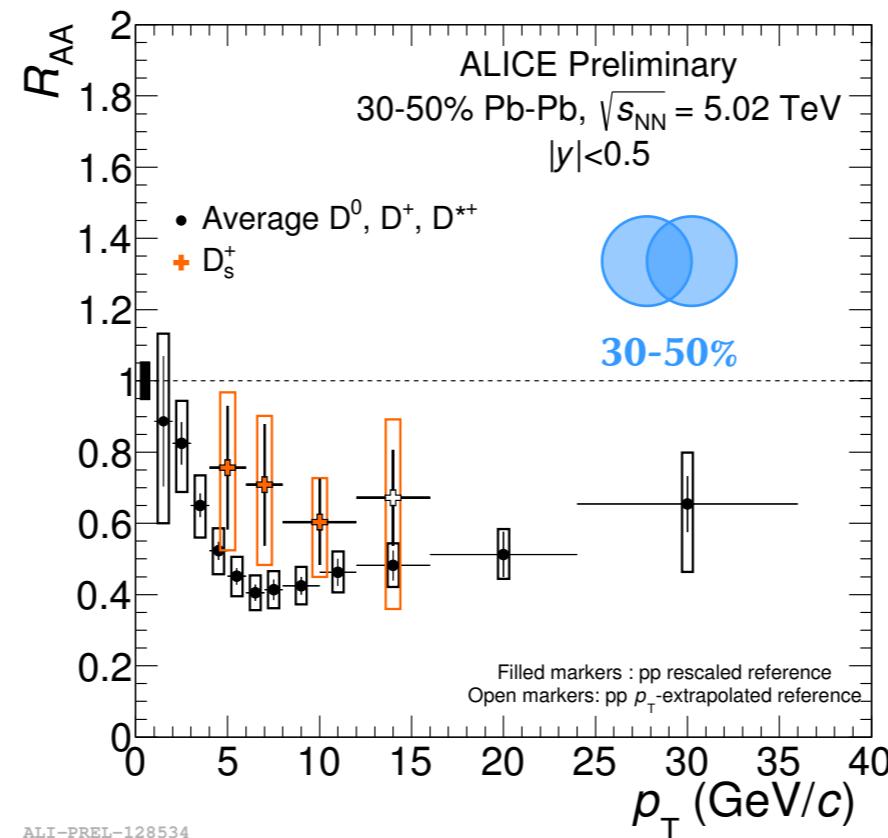
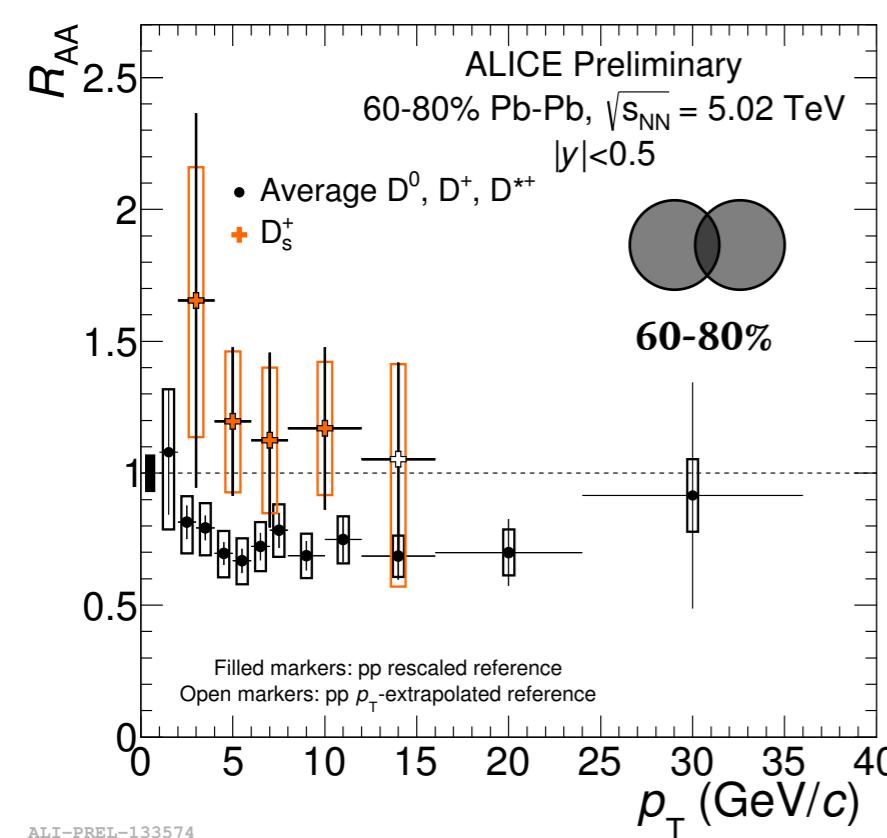
Nuclear modification factor:

$$R_{AA} = \frac{(dN/dp_T)_{AA}}{\langle T_{AA} \rangle \times (d\sigma/dp_T)_{pp}}$$

- Increasing suppression from peripheral (60-80%) to central (0-10%) Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV
 - R_{AA} of D mesons compatible at $\sqrt{s_{NN}} = 2.76$ TeV and $\sqrt{s_{NN}} = 5.02$ TeV
Described by models counterbalancing denser medium and harder spectra
- Improved precision allows us to better access the centrality dependence and p_T -differential R_{AA}



Strange vs. non-strange D mesons

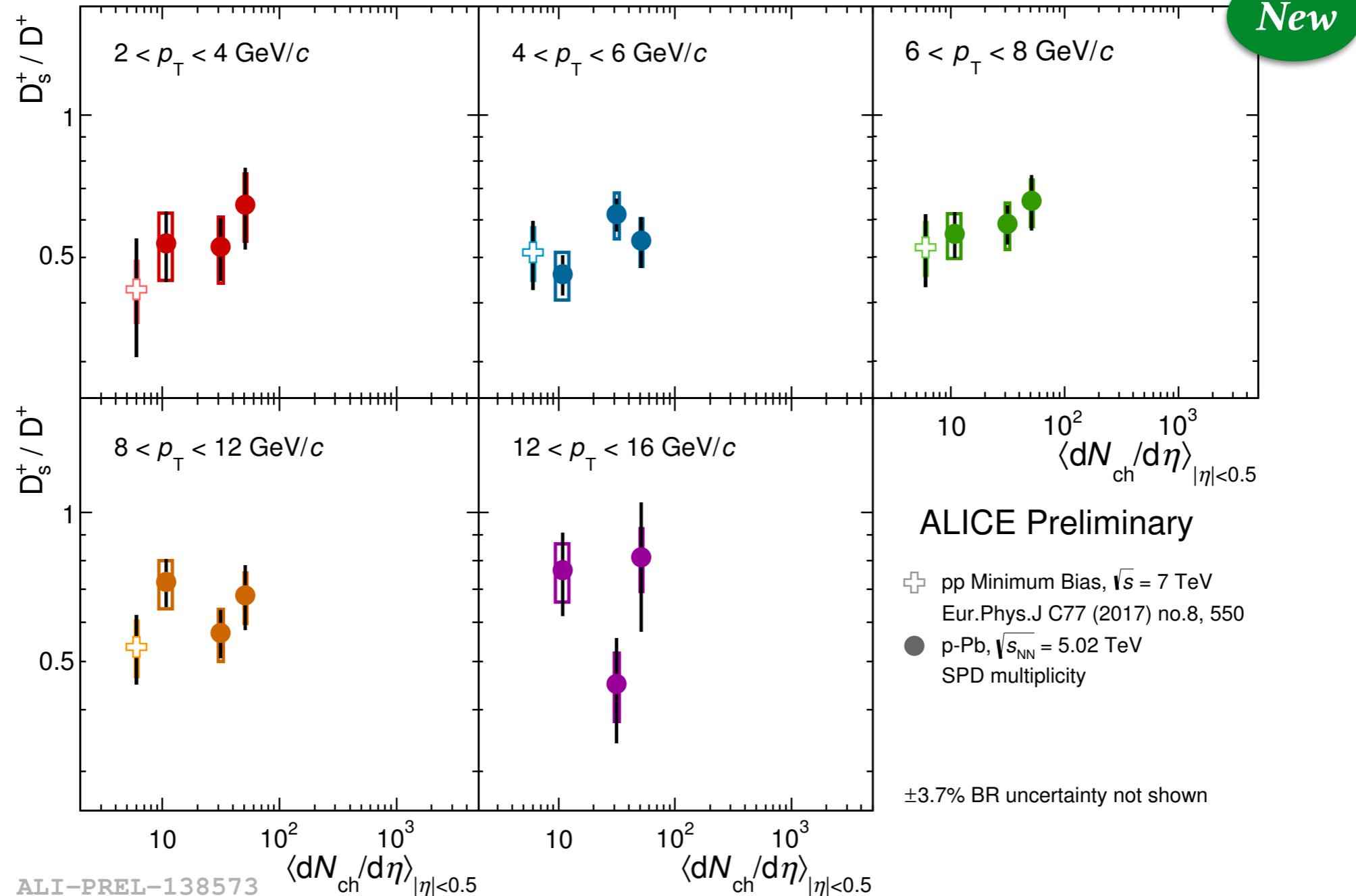


Strange vs. non-strange D mesons:

- Hint of higher R_{AA} of D_s with respect to non-strange D-mesons, at intermediate p_T
→ expected if strangeness enhancement + coalescence play a role for hadronization
- Uncertainties still large to draw a conclusion



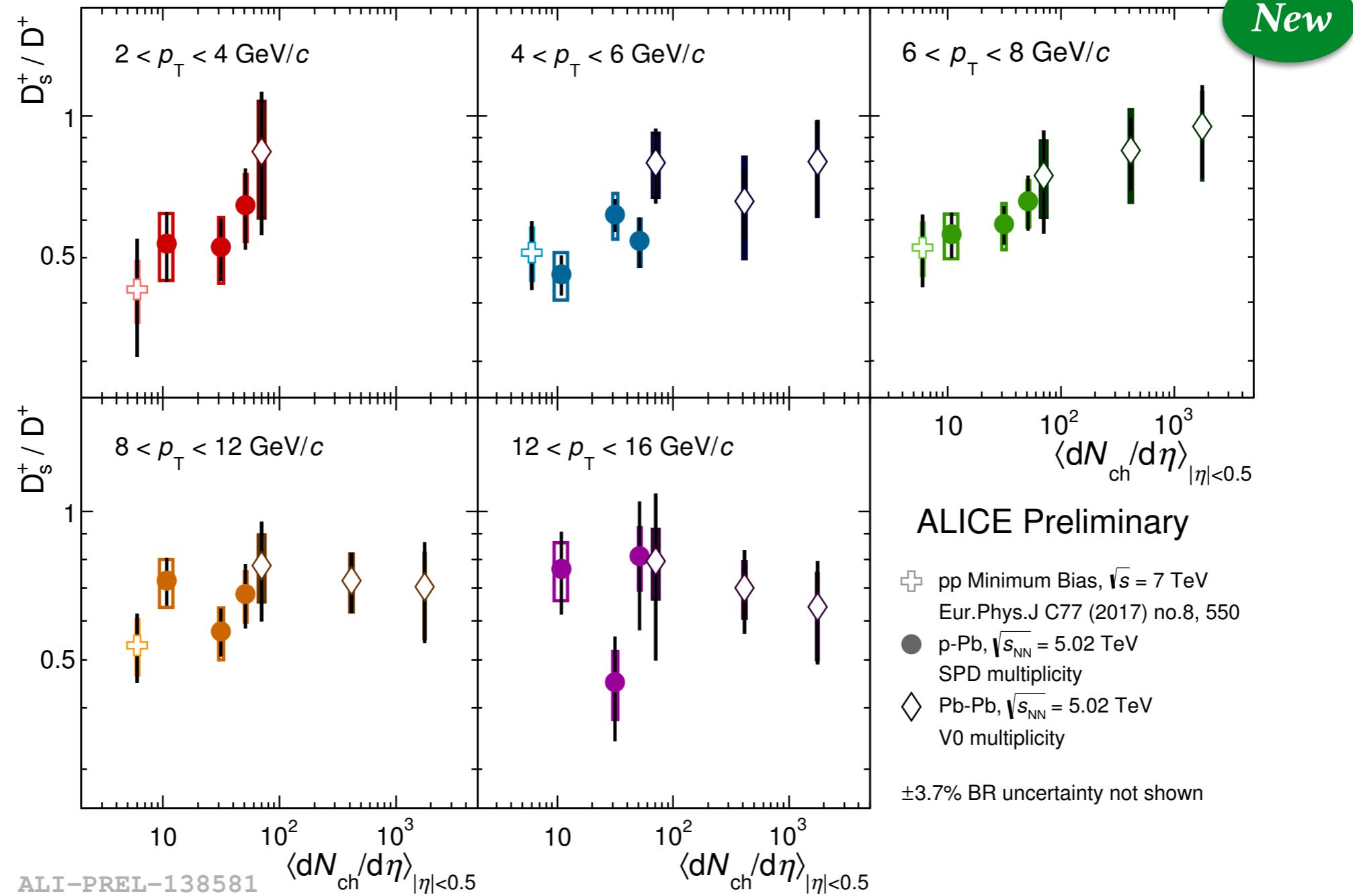
Multiplicity dependence of D_s^+/\bar{D}^+ yields



From pp to p-Pb: no modification of D_s^+/\bar{D}^+ ratio with multiplicity, within uncertainties



Multiplicity dependence of D_s^+/\bar{D}^+ yields

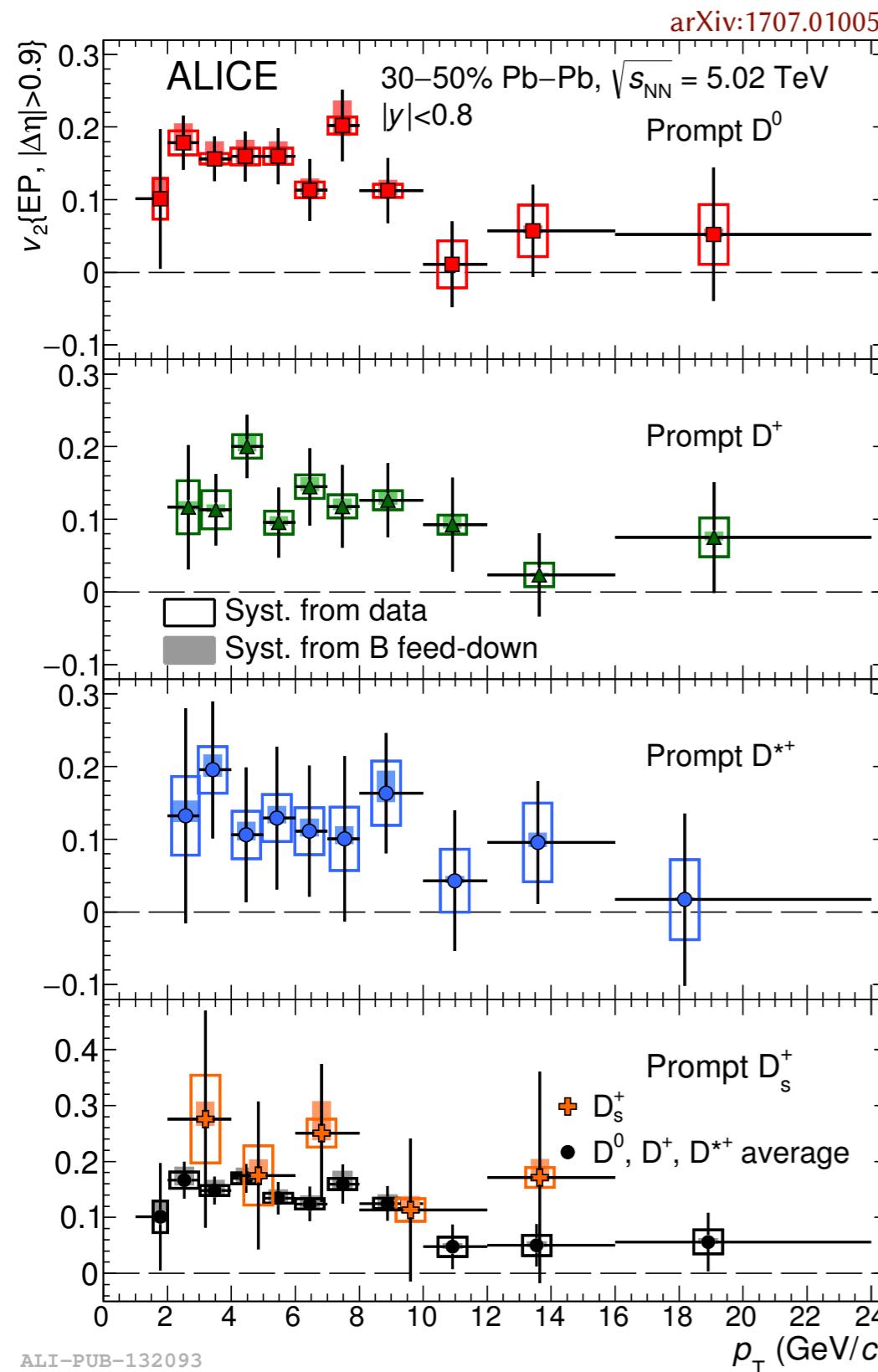


From pp to p-Pb: no modification of D_s^+/\bar{D}^+ ratio with multiplicity, within uncertainties

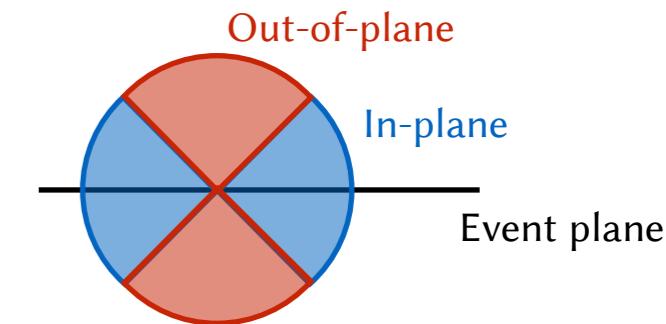
From pp to Pb-Pb: intriguing trend as a function of multiplicity in $2 < p_T < 8$ GeV/c ?
Positive slope at 1σ (statistics only)...



D-meson elliptic flow



D-meson azimuthal anisotropy:



$$v_2\{\text{EP}\} = \frac{1}{R_2} \frac{\pi}{4} \frac{N^{\text{in-plane}} - N^{\text{out-of-plane}}}{N^{\text{in-plane}} + N^{\text{out-of-plane}}}$$

Non-strange D-mesons:

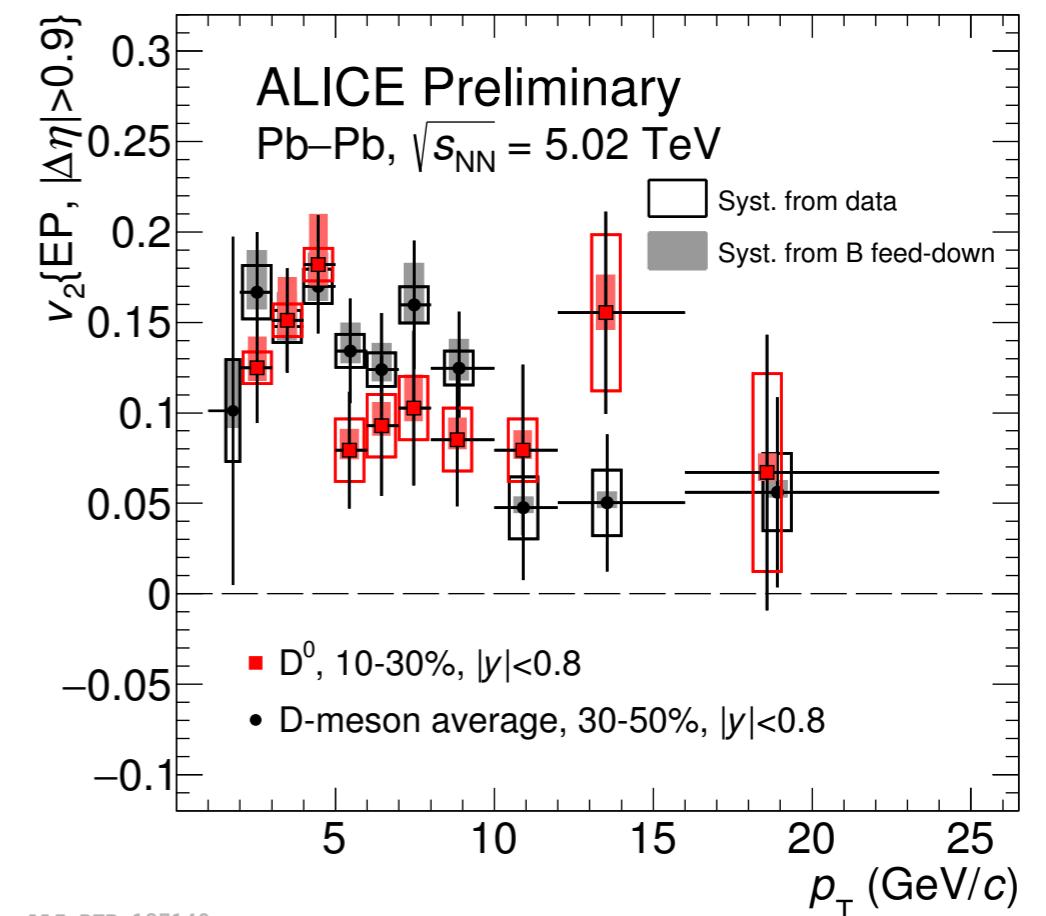
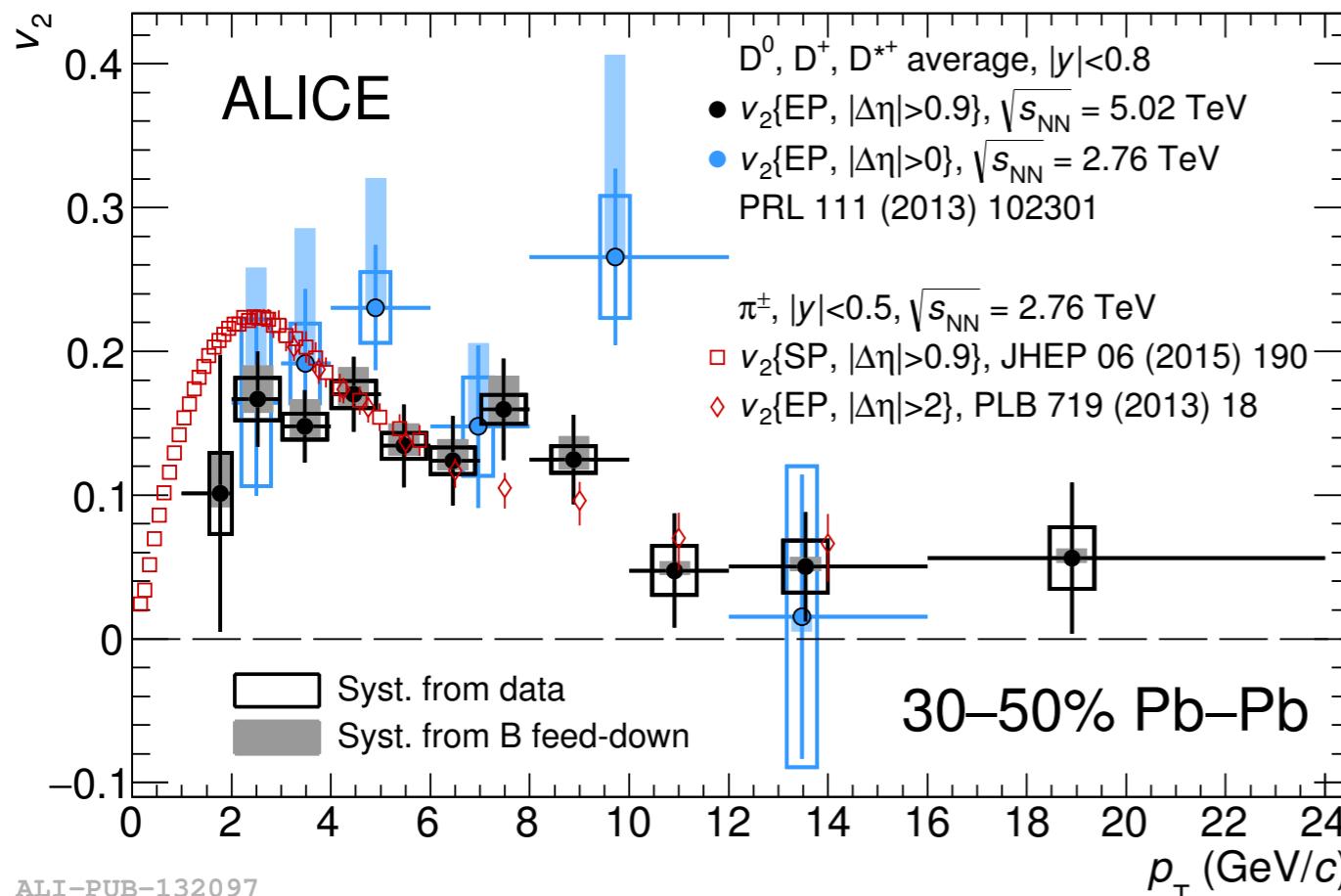
- Positive v_2 of D^0 , D^+ and D^{*+} for $p_T < 10 \text{ GeV}/c$ compatible amongst themselves
- Average (D^0 , D^+ , D^{*+}) $v_2 > 0$ in $2 < p_T < 10 \text{ GeV}/c$

Strange D-mesons: first measurement of $D_s^+ v_2$!

- Positive v_2 with 2.6σ for $2 < p_T < 8 \text{ GeV}/c$
- $D_s^+ v_2$ compatible with the one of **non-strange** D-mesons



D-meson elliptic flow

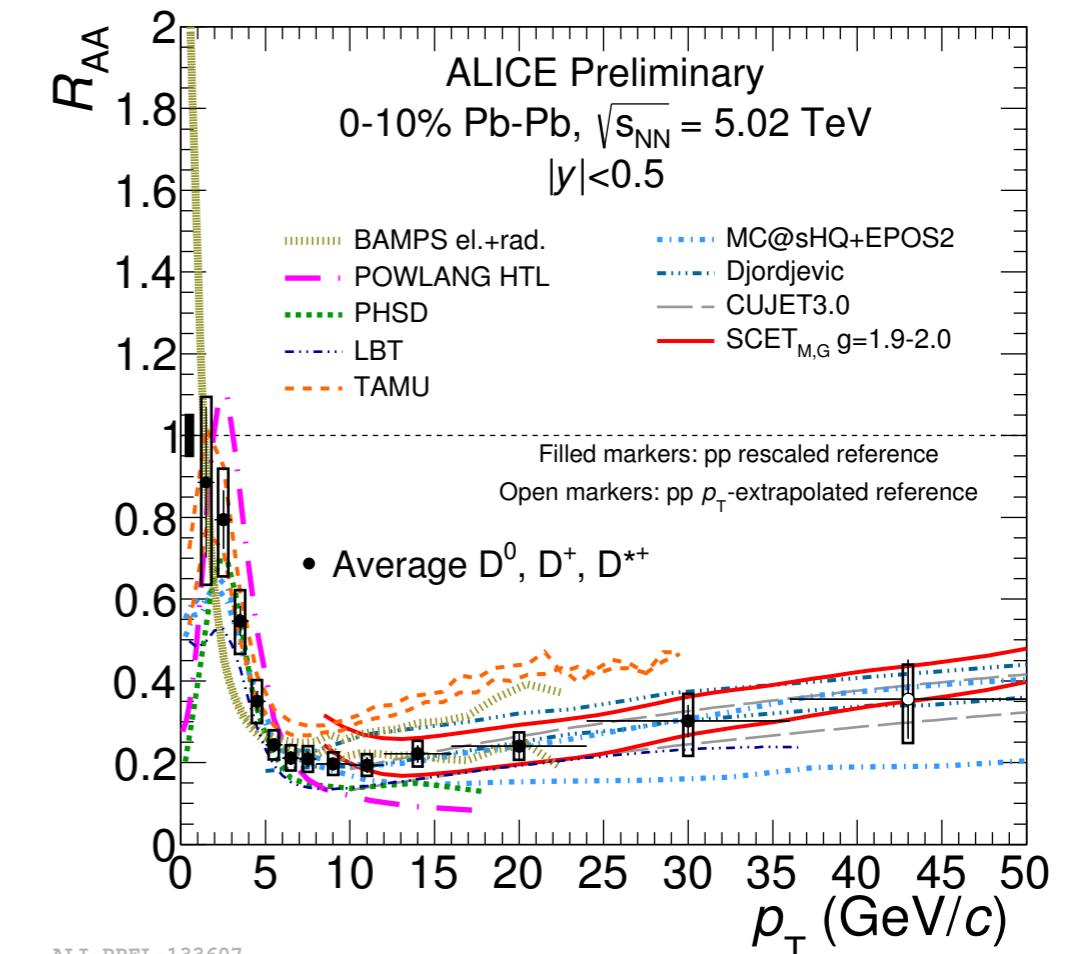
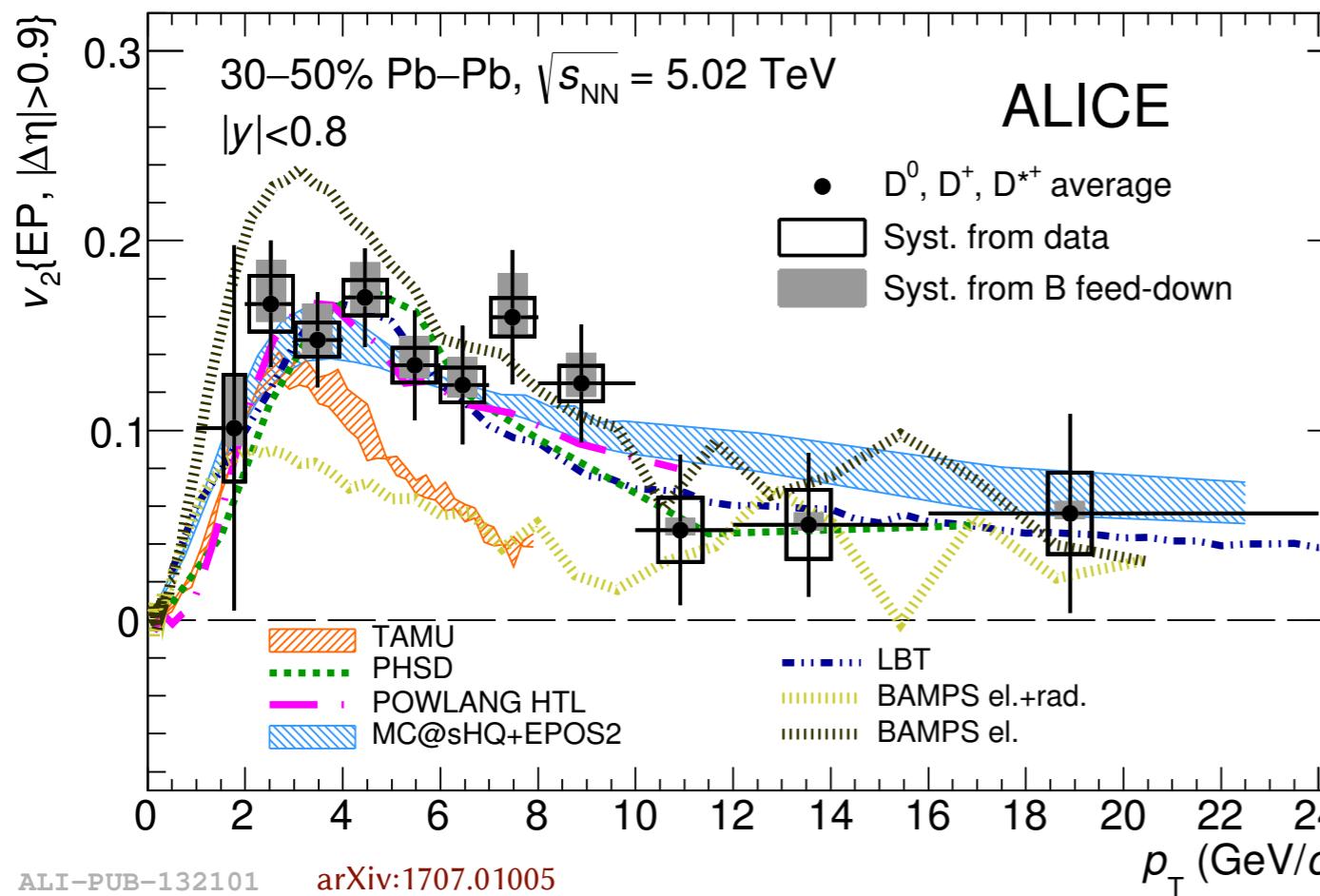


New v_2 measurement:

- Better precision of D-meson v_2 at $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$ than at $\sqrt{s_{\text{NN}}} = 2.76 \text{ TeV}$
- **D-mesons** v_2 similar to **charged π^\pm** v_2 at high p_T
- Similar v_2 in the **10-30%** and **30-50%** centrality classes



Comparison with models



Diversity of precise measurements allow model calculations to be constrained

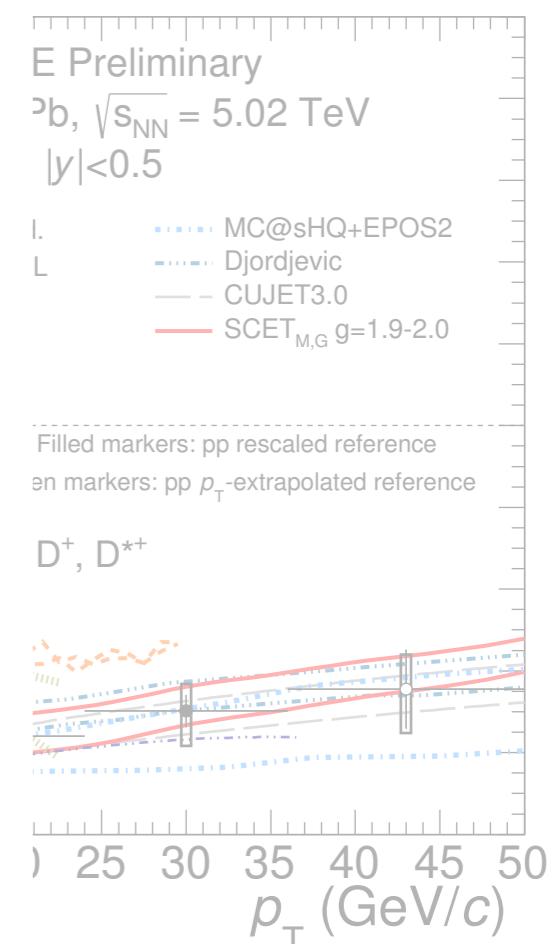
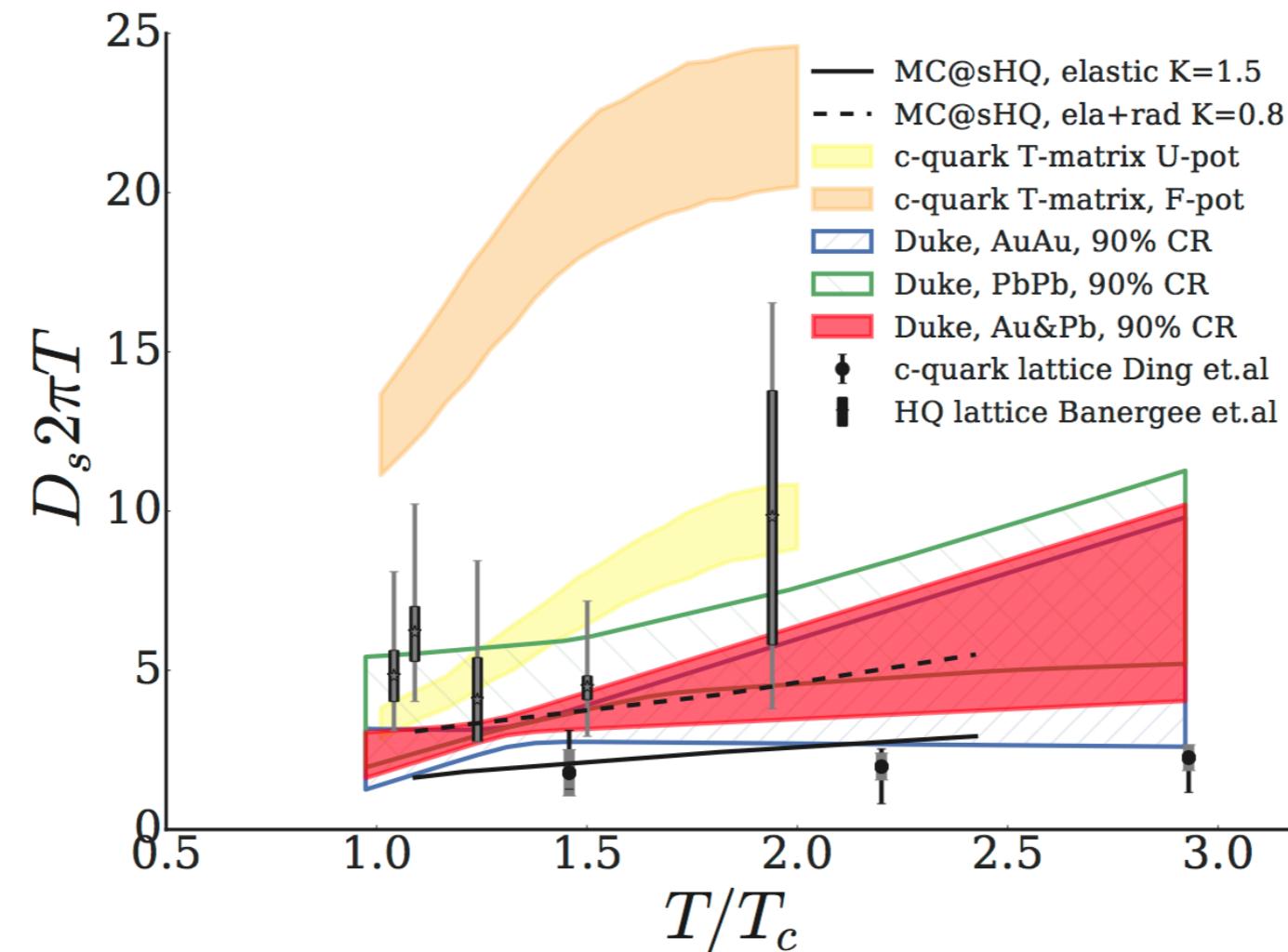
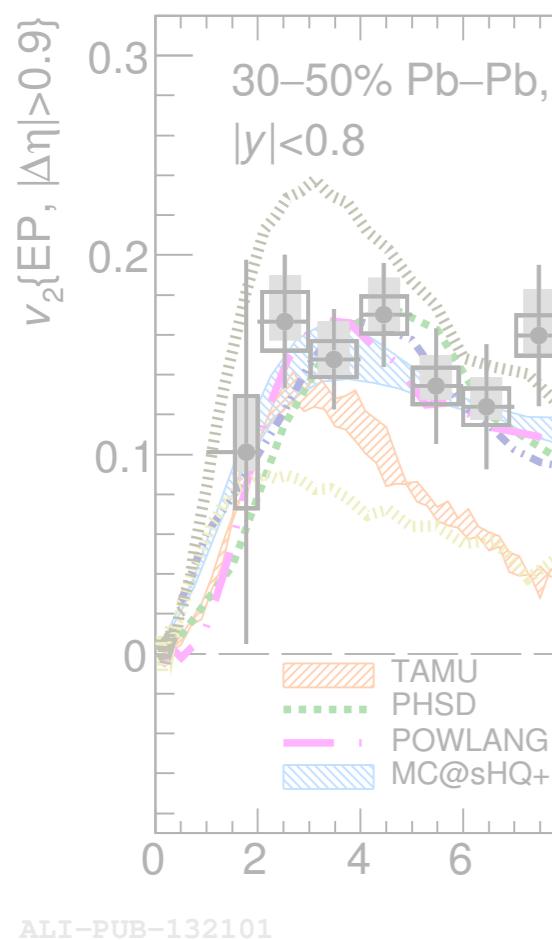
- e.g. rapid v_2 decrease of TAMU likely related to a lack of gluon radiations
→ Estimation of QGP properties

From v_2 fit: models with $\chi^2/ndf < 1$ (LBT, MC@sHQ, PHSD, POWLANG) estimate the spatial diffusion coefficient within $1.5 < 2\pi TD_s(T) < 7$ at T_c → charm-quark relaxation time $\tau_{charm} = (m_{charm}/T)D_s(T) = 3-14$ fm/c

From $v_2 + R_{AA}$: combining several observables at several energies allows for better constraints!



Comparison with models



Diversity of precise measurements allow model calculations to be constrained

- e.g. rapid v_2 decrease of TAMU likely related to a lack of gluon radiations
- Estimation of QGP properties

From v_2 fit: models with $\chi^2/ndf < 1$ (LBT, MC@sHQ, PHSD, POWLANG) estimate the spatial diffusion coefficient within $1.5 < 2\pi TD_s(T) < 7$ at T_c → charm-quark relaxation time $\tau_{charm} = (m_{charm}/T)D_s(T) = 3-14$ fm/c

From $v_2 + R_{AA}$: combining several observables at several energies allows for better constraints!

e.g. using Bayesian method based on D-meson measurements at LHC+RHIC

Xu, Nahrgang, Bernhard, Cao, Bass: arXiv:1704.07800



D-meson measurements from Run 2:

- Better precision of all measurements with respect to Run 1 (e.g. relative uncertainties of $\sigma_{pPb}(D_s^+)$ decreased by >2)
 - New types of measurement: Q_{CP} , $v_2(D_s)$, $q_2\dots$
- Potential to **constrain** model calculations and **extract** QGP properties!

Further improvements expected:

- New pp collisions at $\sqrt{s} = 5.02$ TeV awaited at the end of the year → better pp reference
- ITS Upgrade will further improve the measurement precisions and allow accessing new observables

Upgrade of the ALICE Inner Tracking System

Serhiy Senyukov

Dormy House, Etretat

18:30 - 19:00

→ **Stay tuned!**



Thanks for your attention!

