Evolution of open charm production with event multiplicity with ALICE

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Open charm production measurements: physics motivation

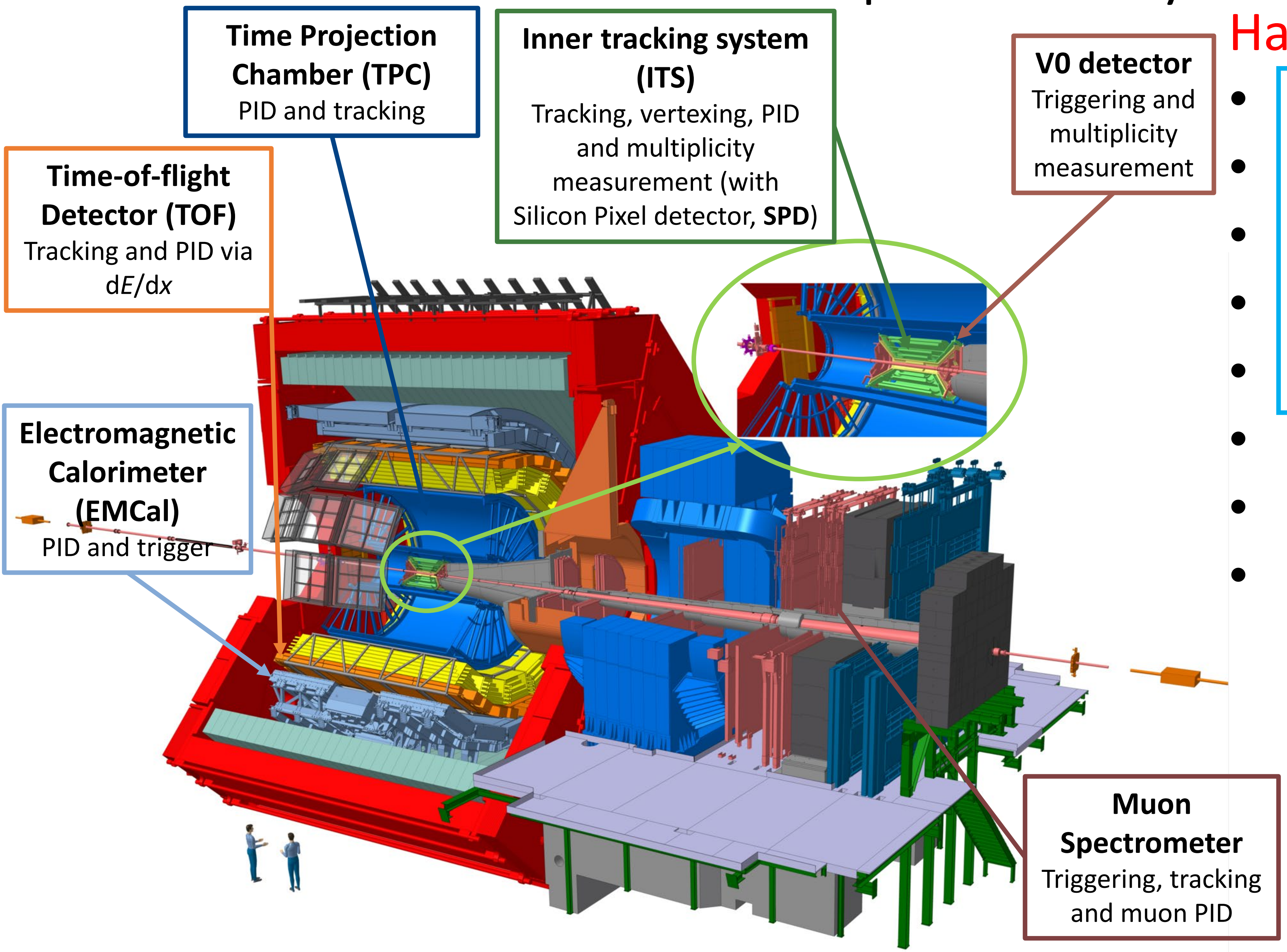
Which collision systems?

- pp collisions → test perturbative QCD calculations
- p-Pb collisions → Inspect Cold Nuclear Matter (CNM) effects

Why studying production vs multiplicity?

- Multi-Parton interactions
- Color Reconnection (CR) mechanisms
- Spectra modification in high multiplicity with respect to Minimum Bias
- Collectivity in high-mult p-Pb collisions?

ALICE and open heavy flavours



Hadronic decays:

In this talk

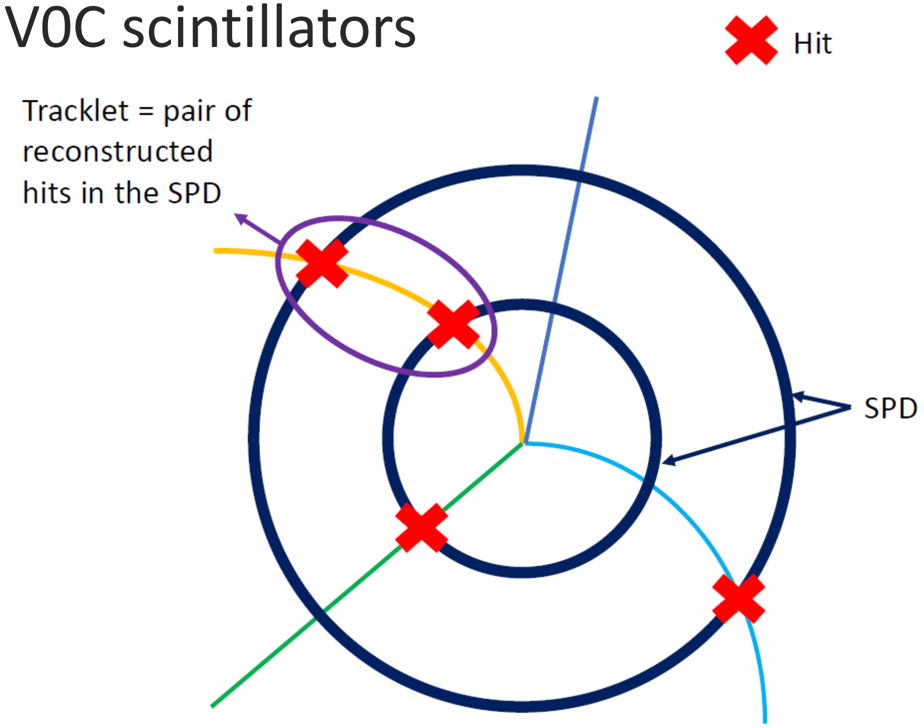
- $D^0 \rightarrow K^- \pi^+$
- $D^+ \rightarrow K^- \pi^+ \pi^+$
- $D^{*+} \rightarrow D^0 \pi^+ \rightarrow K^- \pi^+ \pi^+$
- $D_s^+ \rightarrow \phi \pi^+ \rightarrow K^+ K^- \pi^+$
- $\Lambda_c^+ \rightarrow p K^- \pi^+$ & $\Lambda_c^+ \rightarrow p K_s^0$
- $\Sigma_c^0 \rightarrow \Lambda_c^+ \pi^+$ & $\Sigma_c^0 \rightarrow \Lambda_c^+ \pi^+$
- $\Xi_c^0 \rightarrow \Xi^- \pi^+$ & $\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+$
- $\Omega_c^0 \rightarrow \Omega^- \pi^+$

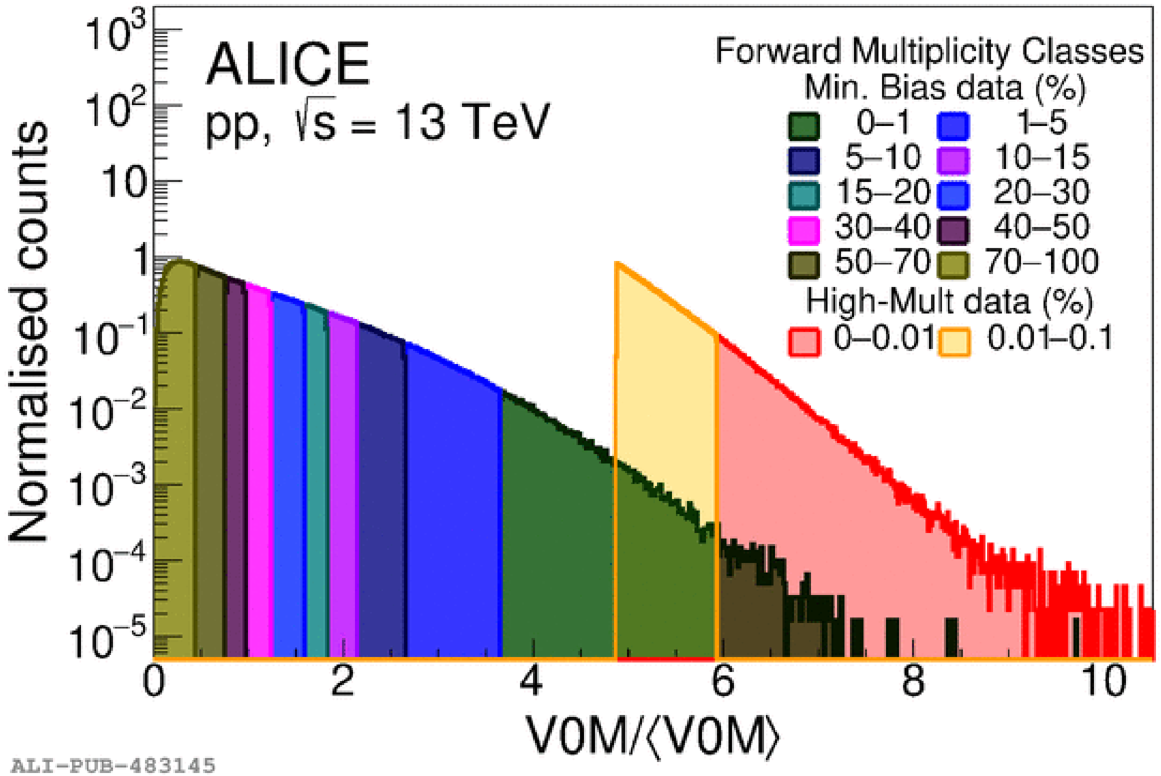
Semi-leptonic decays:

- $B, D \rightarrow e + X$
- $B, D \rightarrow \mu + X$
- $\Xi_c^0 \rightarrow \Xi^- e^+ \nu_e$
- $\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e$

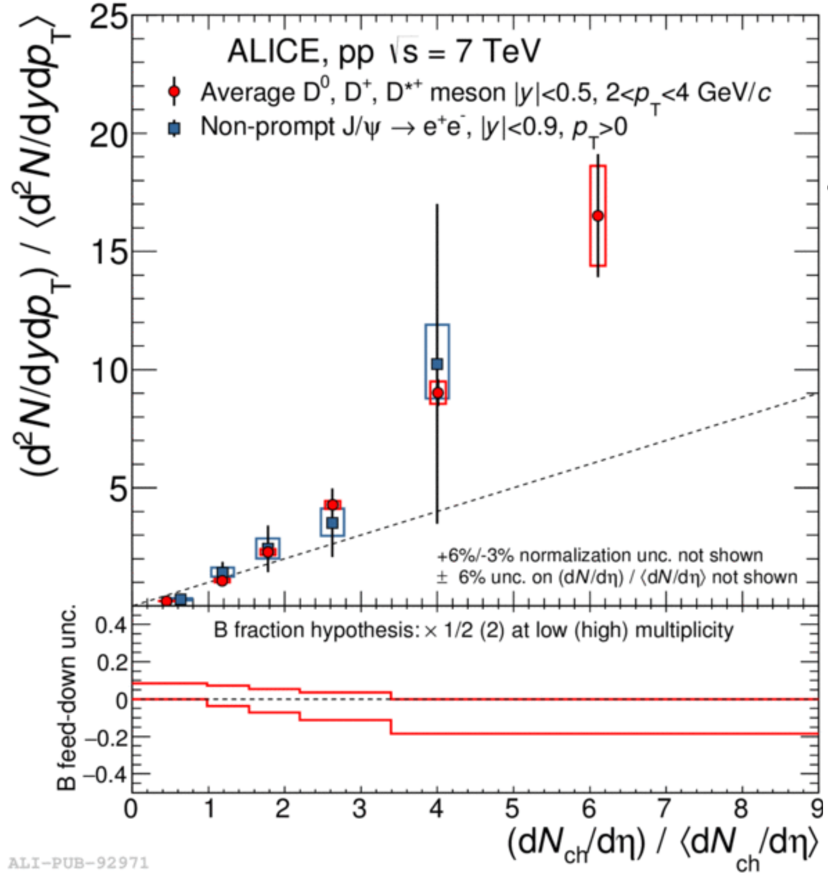
Multiplicity measurement

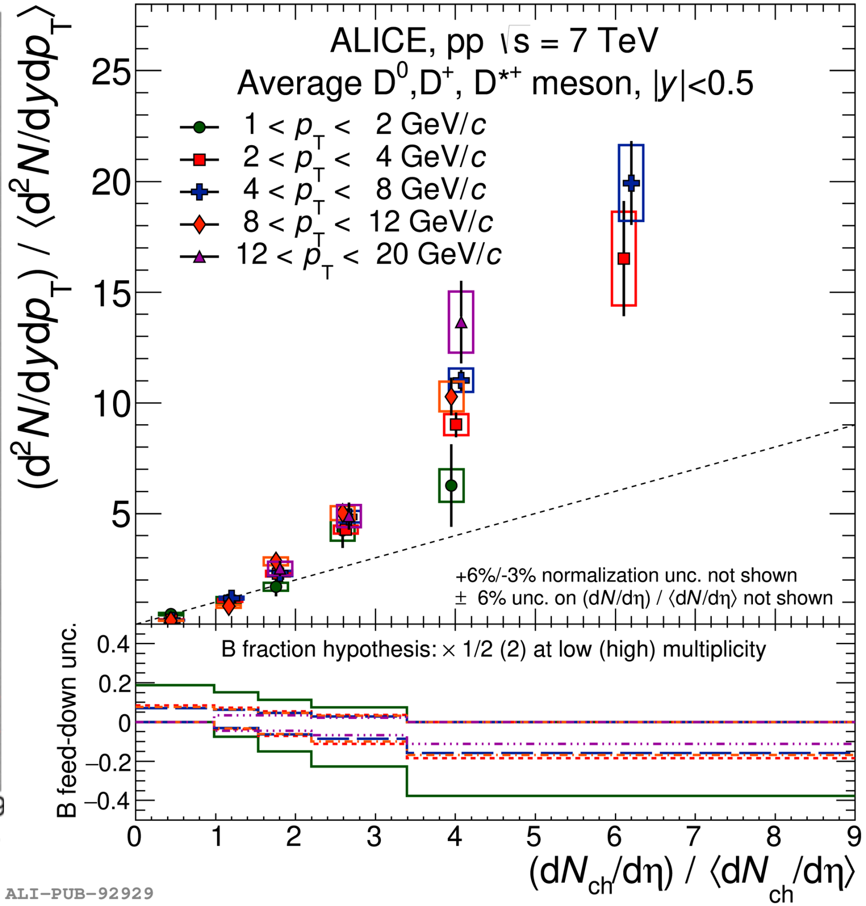
- Two methods:
  - SPD tracklets → track segments built from two hits in SPD layers in line with reconstructed primary vertex
  - V0M percentile → multiplicity estimation based on the percentile distribution of the V0M amplitude, which is a weighted sum of charge deposition in the V0A and V0C scintillators





Run 1 results at $\sqrt{s} = 7$ TeV





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- Self normalised yield vs charged particle multiplicity

$$\frac{d^2N/(dydp_T)}{\langle d^2N/(dydp_T)\rangle} = \frac{Y_{mult}^{corr}}{Y_{int}^{corr}}$$

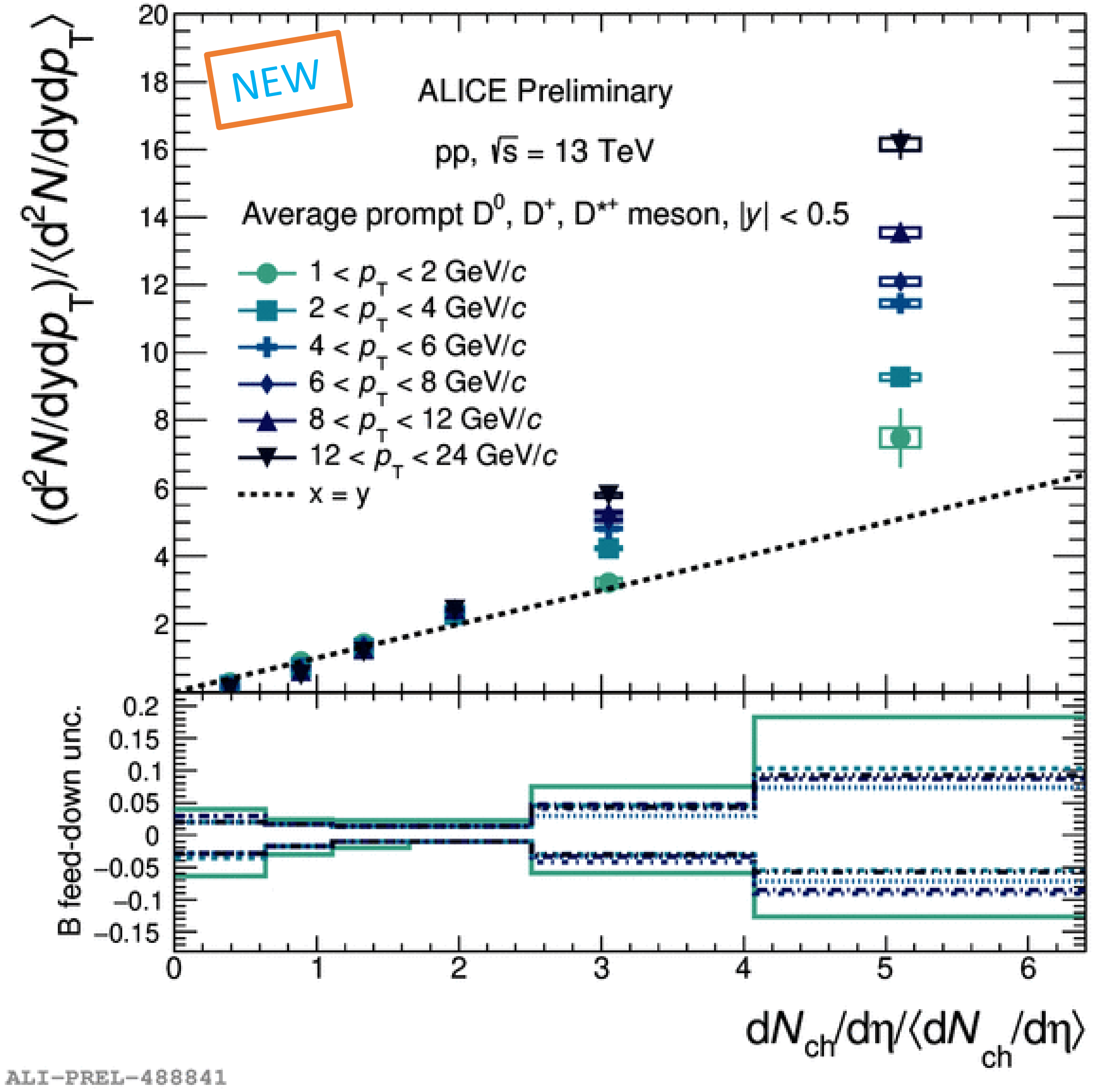
with $Y_{mult/int}^{corr}$ = corrected yield in multiplicity interval/integrated case

- D-mesons and J/ψ measurements at $\sqrt{s} = 7$ TeV show a faster than linear increasing trend and no strong p_T dependence within uncertainties

D mesons self normalised yield in pp at $\sqrt{s} = 13$ TeV

New and more precise 13 TeV results show faster than linear increase vs multiplicity

Higher p_T intervals show a steeper self normalised yield trend than lower ones → significant dependence



D-meson self normalised yield vs models in pp at $\sqrt{s} = 13$ TeV

Measurements compared with models:

*1. EPOS3 generator with initial conditions followed by a hydrodynamical evolution (EPOS + hydro)

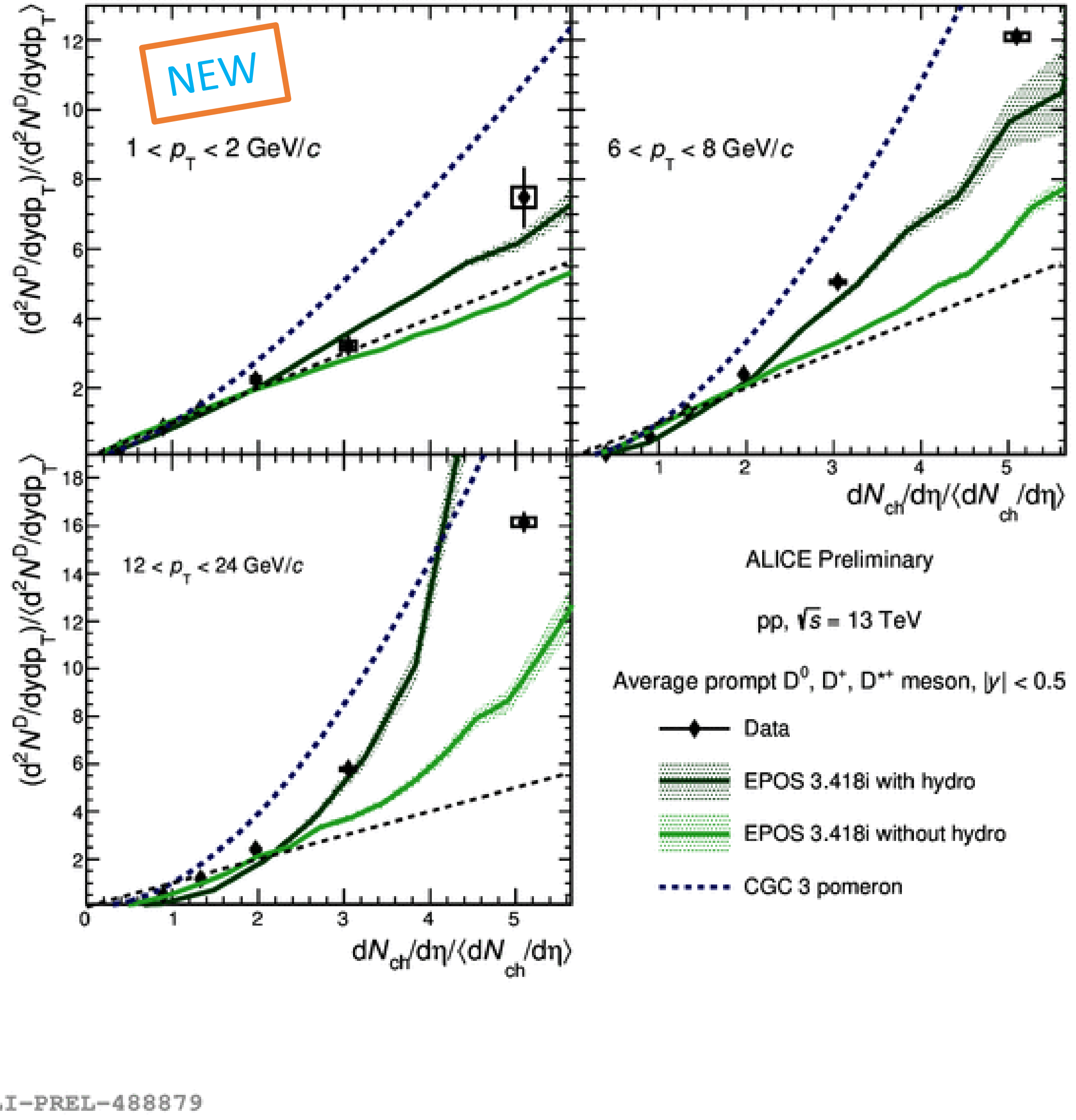
↓ Closer to data

*2. EPOS3 with no hydro

↓ Underestimates data

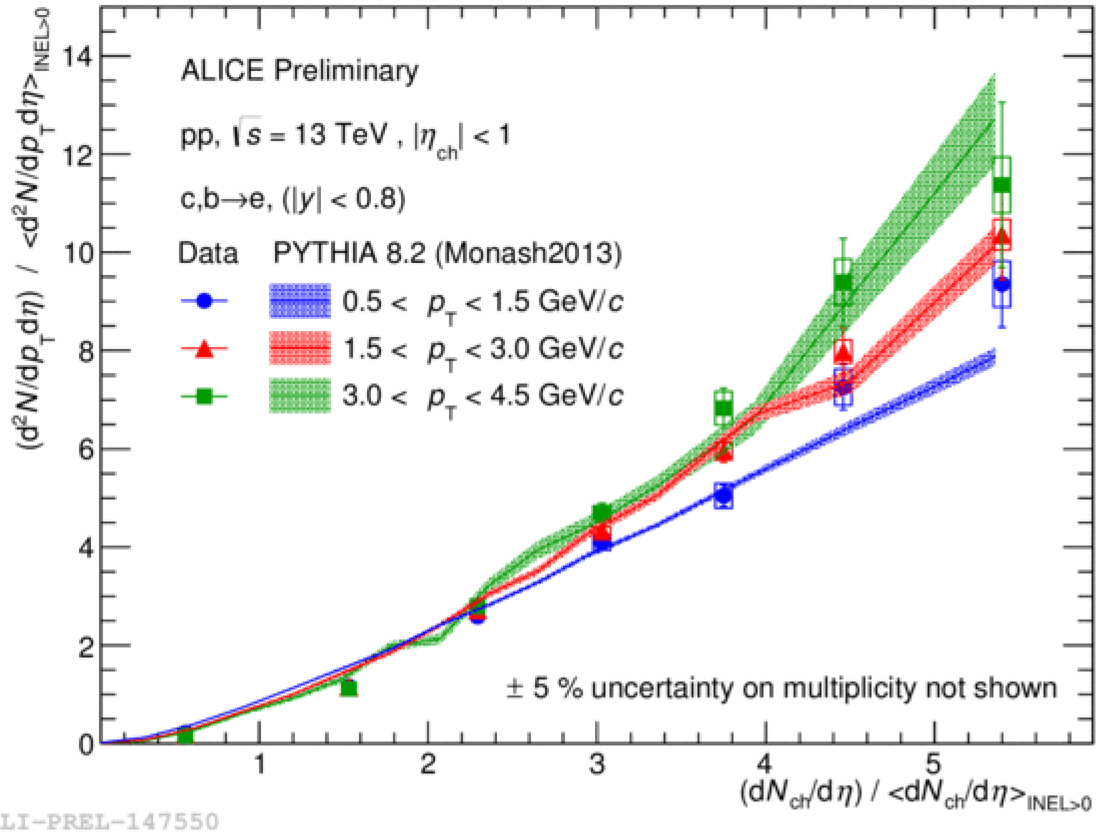
*3. 3-Pomeron Color Glass Condensate (CGC)

↓ Overestimates data



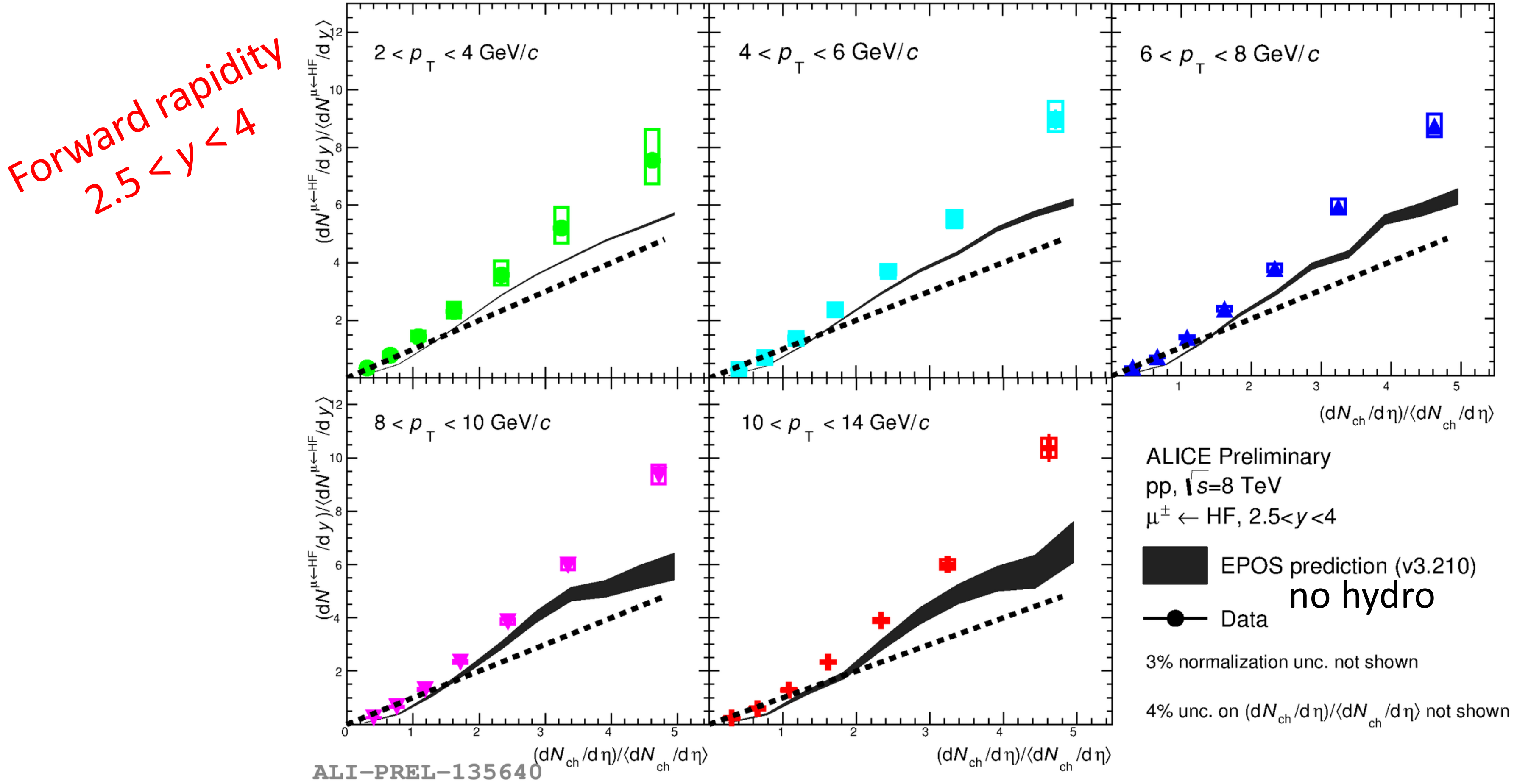
* [K. Werner et al, Phys. Rev. C 89, 064903 (2014)]
* [I. Schmidt et al, Phys. Rev. D 101, 094020 (2020)]

c,b → e in pp at $\sqrt{s} = 13$ TeV



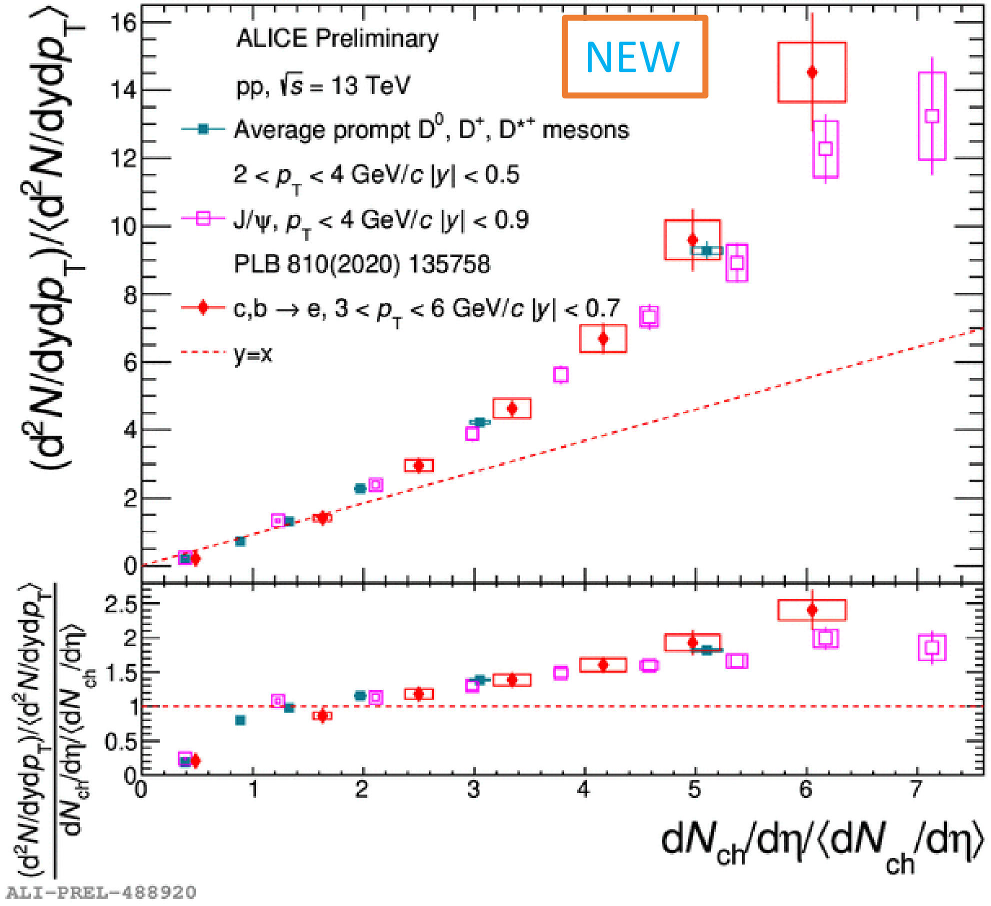
Heavy-flavour decay electrons described well by PYTHIA 8.2 Monash 2013 tune → Color Reconnection and Multiple Parton interactions included

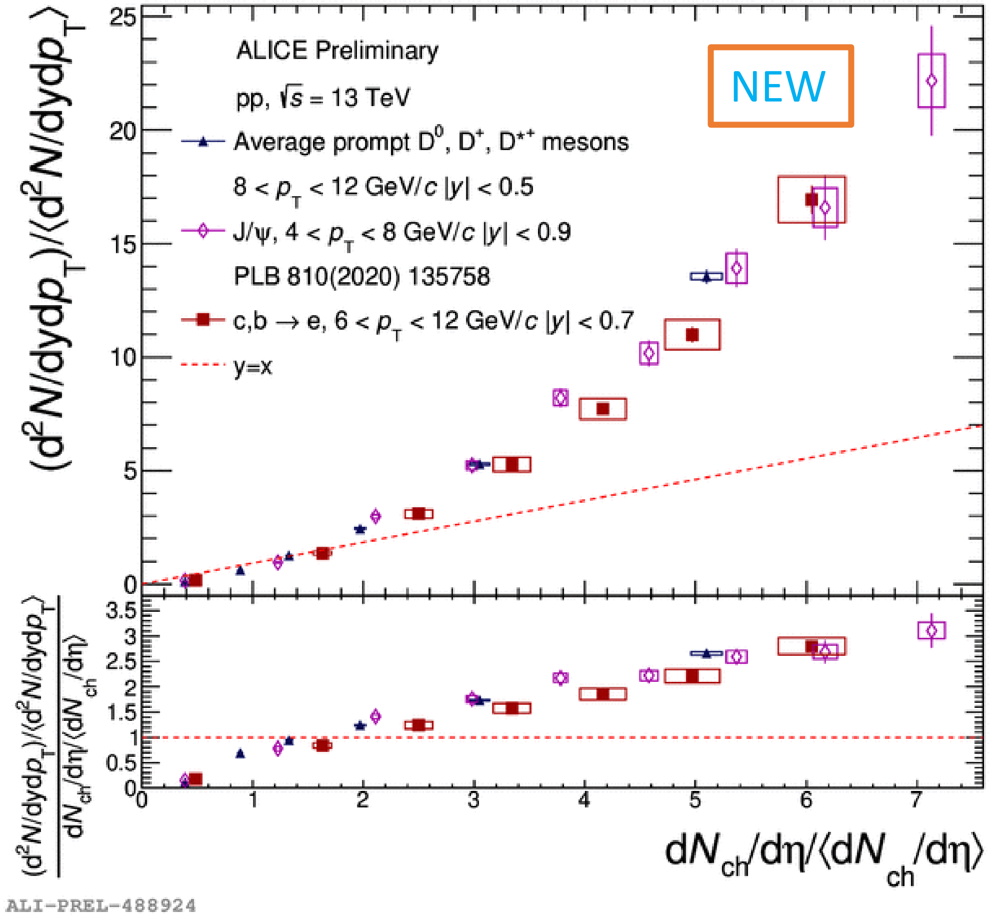
Heavy Flavour $\mu^{\pm}$ yield in pp at $\sqrt{s} = 8$ TeV



- Faster than linear trend observed similarly to the other heavy-flavour particles → weaker p_T dependence compared to D mesons
- EPOS predictions underestimate the muon production

Particles production comparison in pp at $\sqrt{s} = 13$ TeV





Self normalised yields of J/ψ, electrons from heavy-flavour decays and average D mesons compatible in similar p_T ranges

Λ_c^+/D^0 in pp at $\sqrt{s} = 13$ TeV

- Measurements show a dependence of the Λ_c^+/D^0 yield ratio vs multiplicity

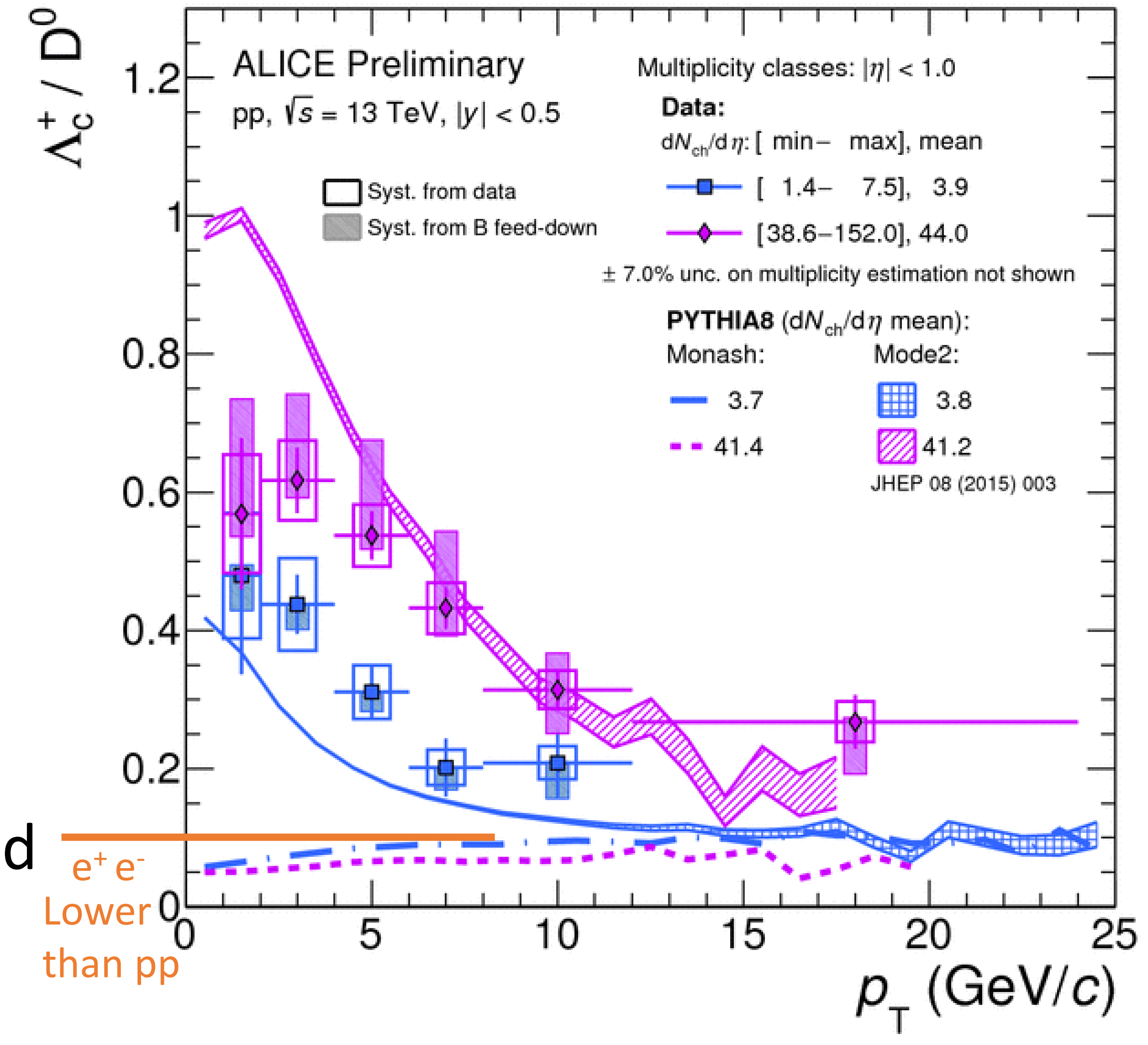
  ↓

  Modification of hadronization mechanisms with multiplicity

- PYTHIA8 Monash tune doesn't describe data

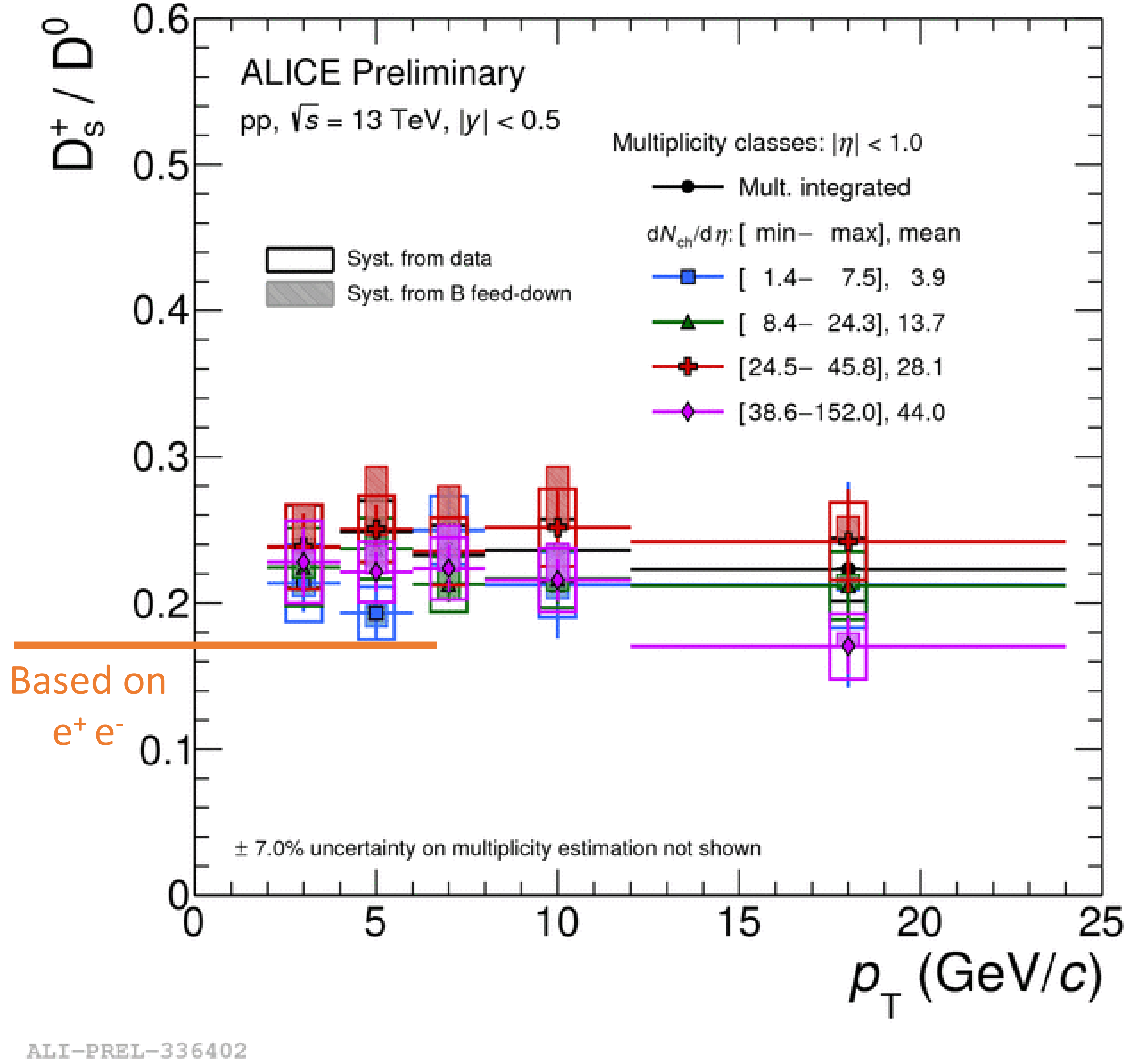
  ↓

PYTHIA Enhanced CR Mode 2 tune* describes the measured p_T trend and the multiplicity trend



* [Christiansen et al, JHEP 2015, 3 (2015)]

D_s^+/D^0 in pp at $\sqrt{s} = 13$ TeV

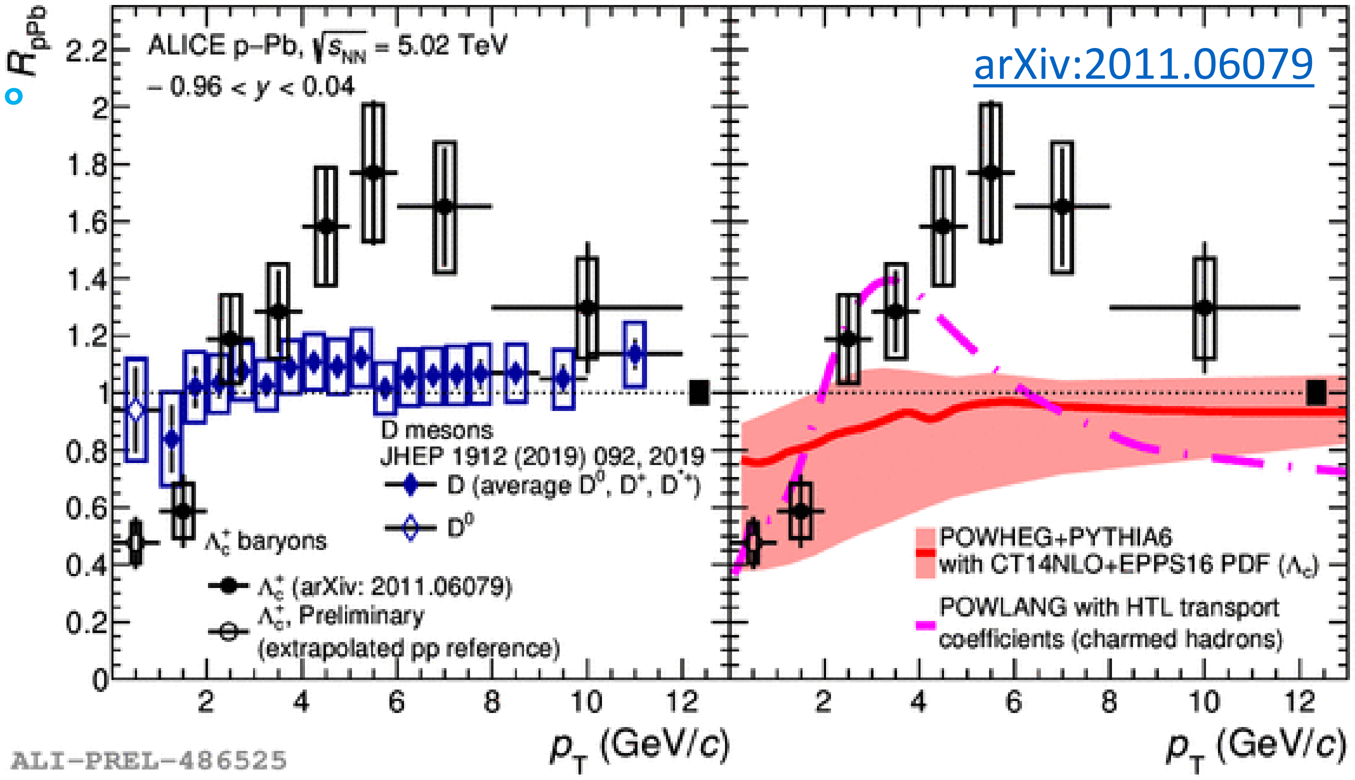


- Results show no clear multiplicity dependence
- Compatible with the average of the p_T integrated measurements performed at e^+e^- collisions [L. Gladilin, Eur. Phys. J. C 75, 19 (2015)]

$R_{\rm pPb}$ at $\sqrt{s_{\rm NN}} = 5.02$ TeV

NEW for Λ_c^+ down to $p_T = 0$ GeV/c

- D mesons $R_{\rm pPb}\approx 1$
- D mesons and Λ_c^+ compatible with POWHEG+PYTHIA6 at low p_T
- Λ_c^+ significant suppression in $p_T < 2$ GeV/c → above unity elsewhere → compatible with POWLANG up to 4 GeV/c
- Trend hints a deviation from model predictions at intermediate-high p_T → radial flow in p-Pb or modification of hadronization mechanism?



$$R_{\rm pPb} = \frac{1}{A}\frac{d\sigma_{\rm pPb}/dp_T}{d\sigma_{\rm pp}/dp_T}$$

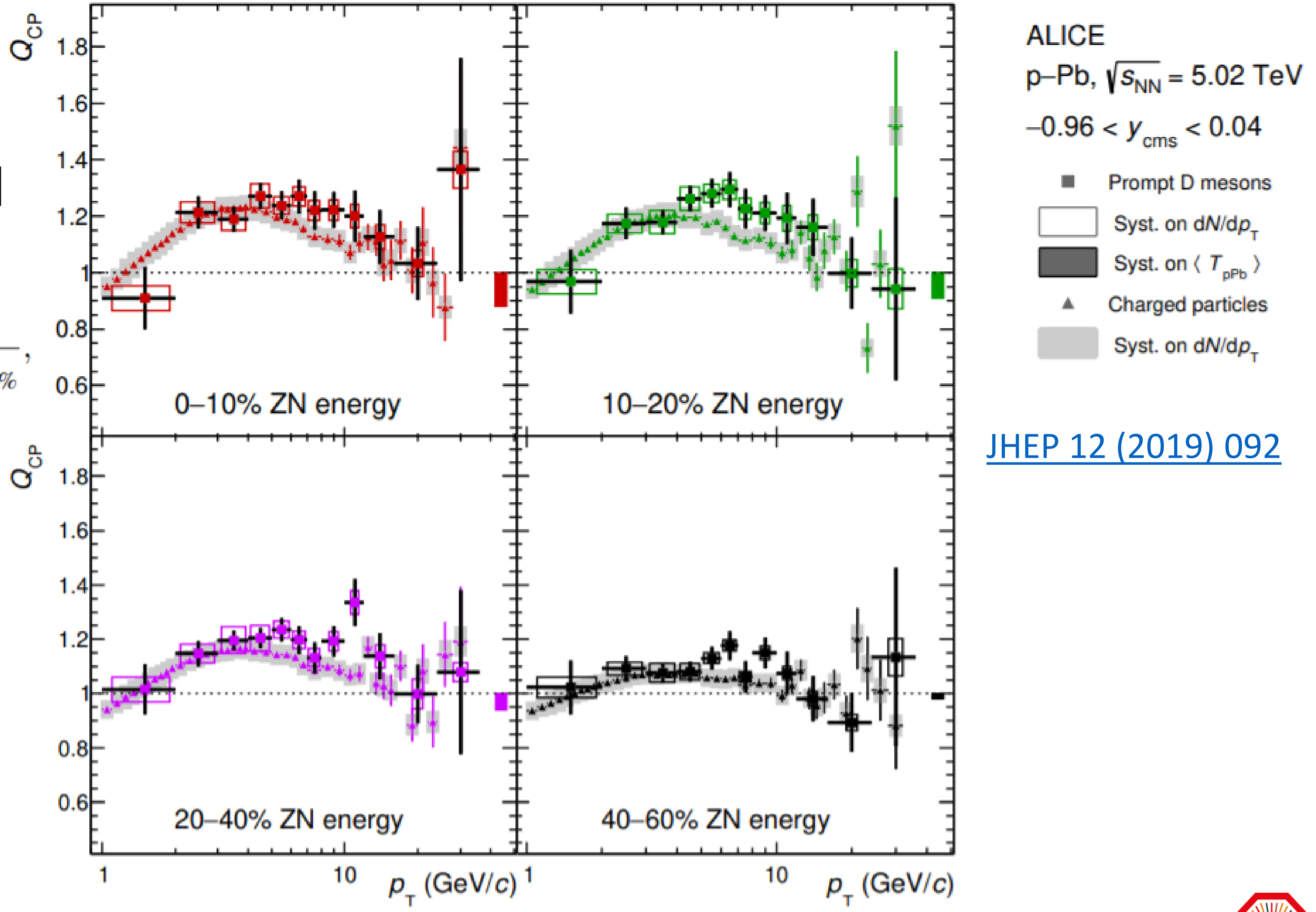
D-meson Q_{cp} in p-Pb at $\sqrt{s_{NN}} = 5.02$ TeV

- Ratio of prompt D meson yield with 60-100% multiplicity class calculated using the formula

$$Q_{CP} = \frac{(d^2N^{\text{prompt D}}/dp_T dy)^{i}_{p-Pb} / \langle T_{pPb} \rangle_i}{(d^2N^{\text{prompt D}}/dp_T dy)^{60-100\%}_{p-Pb} / \langle T_{pPb} \rangle_{60-100\%}},$$

where $\langle T_{pPb} \rangle$ is the nuclear overlap function

- Hint of an enhancement of the Q_{cp} at intermediate p_T due to radial flow



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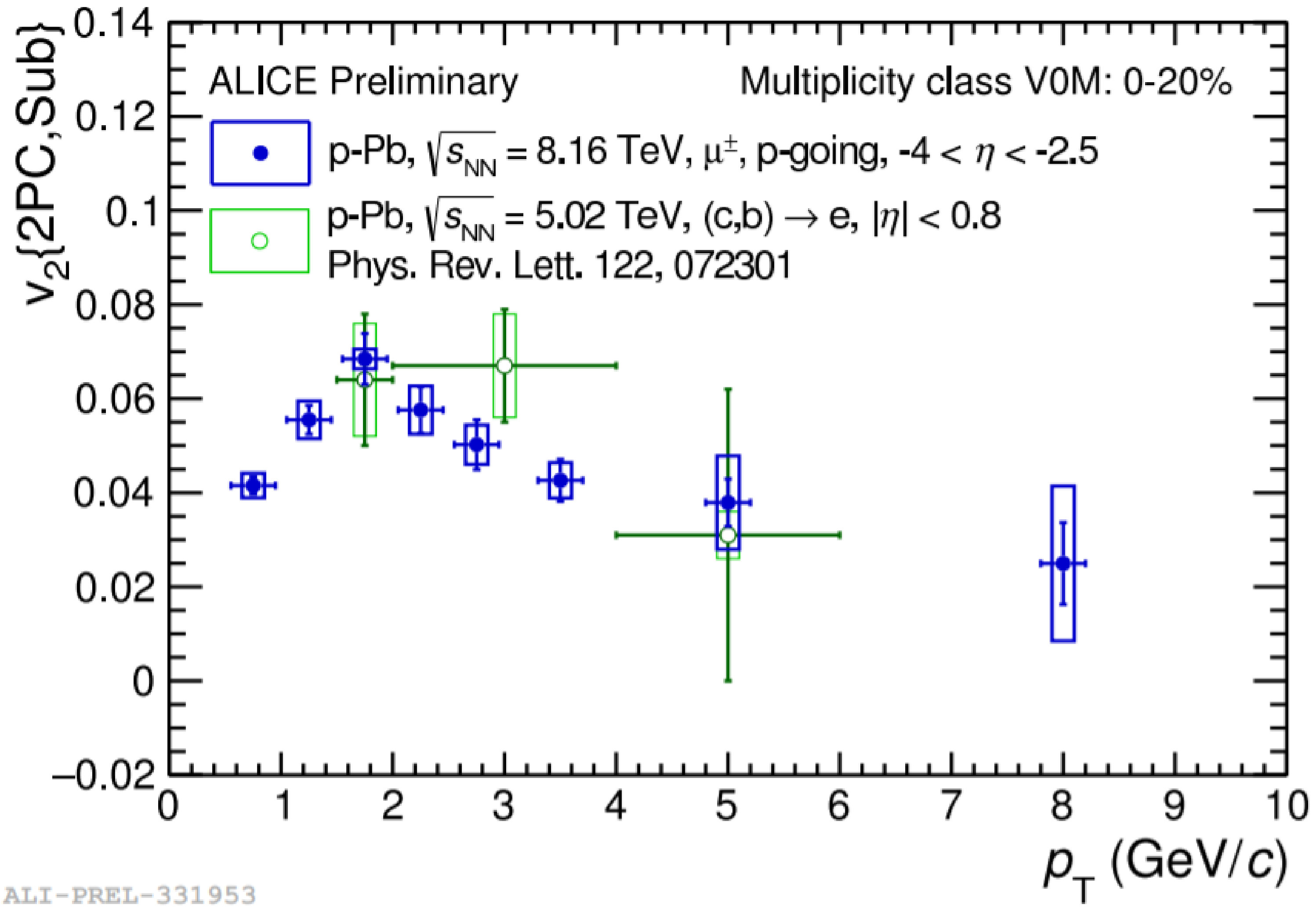
Elliptic flow e and μ in p-Pb collisions



ALI-PREL-331953

- Heavy flavour decay electrons v_2 at midrapidity compatible with muons at forward rapidity
- Leptons show positive elliptic flow observed in 0-20% V0M multiplicity class

↓

Indication of collectivity in the collision system

Summary

pp collisions:

- Average D mesons, J/ψ and heavy-flavour hadron decays electrons compatible in similar p_T intervals

  Trends faster than linear vs multiplicity and significant p_T dependence

  Average D reproduced fairly well by EPOS3 with hydro, heavy flavour electrons well by Monash 2013

- Λ_c^+/D^0 enhancement compared to e^+e^- and with increasing multiplicity (not observed in D_s^+/D^0) → well reproduced by PYTHIA8 mode 2

  Hint of modification of hadronization mechanisms vs multiplicity

  Non-universality of charm fragmentation in different collision systems

  Check Jinjoo talk for more

- Muons from heavy-flavour hadron decays production at forward rapidity faster than linear vs multiplicity → weak p_T dependence

p-Pb collisions:

- Λ_c^+ production at intermediate-high p_T not fully understood → R_{pPb} compatible with POWLANG and with POWHEG+PYTHIA6 in lower intervals
- Indication of collectivity in p-Pb collisions

Backup

Model references

- EPOS [Phys. Rev. C 89, 064903 (2014)]
  - With Hydrodynamic evolution → initial conditions set by the EPOS generator and particles produced at "freeze-out" directly from the flowing medium
  - Without Hydro

- 3-pomeron Color Glass Condensate → included contribution to charm quarks from 3-gluons fusion
  [Phys. Rev. D 49, 2233-3352 (1994)] [Phys. Rev. D 50, 2225 (1994)]

- Pythia8
  - With Colour reconnection [JHEP 08 (2015) 003] → Added junctions connection topologies enhancing the formation of baryons → mode parameters consider string reconnection, time dilation etc.
  - Without

D mesons and HFe in p-Pb at $\sqrt{s} = 5.02$ TeV

- Average D mesons and HFe compatible in lower and middle multiplicity intervals
- Trend faster than linear shown even in this collision system
- EPOS3, with and without hydro, reproduces well the measurements → better results with hydro at higher multiplicity